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The overall aim of this research is to gain insight into the etiology of tibial stress fractures. Three dimensional motion analysis data along with structural data will be collected from 40 subjects (200 at each site) over a 3-year period. 30 of the subjects will have sustained a tibial stress fracture prior to the study and the other 370 will have not. Subjects will be recruited primarily from track teams, running clubs, and physicians local to the University of Delaware and University of Massachusetts. Within this Annual Report, information concerning adherence to work objectives, preliminary results with respect to the proposed hypotheses, and reportable outcomes are presented for the third year of the investigation. Overall, we have adhered to most work objectives and have proposed plans for rectifying any discrepancies. The preliminary analysis of the data demonstrates encouraging results and support of most hypotheses.

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INTRODUCTION

Stress fractures can be extremely costly to the military in terms of both time and medical expenses. The tibia is a common site for such injuries and has been most often associated with running, an activity common to all military training. Stress fractures are among the top 5 cited lower extremity injuries sustained by runners (Clement et al., 1981; Kowal, 1980; James et al., 1978; Jones, 1983; Pagliano and Jackson, 1980; Reinker and Ozburne, 1979). They are among the most serious of running-related overuse injuries as they take long to heal and if untreated, can progress to a macrofracture. Females are a growing military contingency and appear to be particularly susceptible, as it has been noted that they are twice as likely to experience a stress fracture as their male counterparts (Brudvig et al, 1983; Pester and Smith, 1992; Reinker and Ozburne, 1979).

Structural and biomechanical factors have been suggested in the cause of stress fractures. However, these mechanisms are not well understood. Therefore, the purposes of this study are 1) to compare the structure and mechanics of runners who have sustained a tibial stress fracture to those who have not, 2) to gain an understanding of which combination of factors (structural and/or biomechanical) are predictive of tibial stress fractures, and 3) to assess whether mechanics are altered following a tibial stress fracture. Once the factors associated with stress fractures are identified, future work will focus on formation and testing of a simple screening tool to facilitate identification of those at risk.

This is a dual-site investigation (University of Delaware & University of Massachusetts, Amherst) which began on September 1, 2000 and has been under investigation for three years. This Annual Report will focus on intermediate results after the third year of the study.

BODY

Summary of Methodology

The overall aim of this research is to gain insight into the etiology of tibial stress fractures. Three dimensional motion analysis data along with structural data will be collected from 400 subjects (200 at each site) over a 3-year period. A minimum of 30 subjects will have sustained a tibial stress fracture prior to the study. Subjects will be recruited primarily from track teams, running clubs, and physicians local to the University of Delaware and University of Massachusetts. All subjects will be females between the ages of 18 and 45 and will be free of lower extremity injury at the time of testing. Lower extremity kinematics and kinetics will be collected during running. In addition, radiographs of both tibiae will be taken as well as clinical measures of lower extremity alignment. Subjects will then report their exposure data (mileage, intensity, terrain) as well as any injuries they have sustained each month via a custom developed webpage which will serve as a database for this information. If a subject reports a tibial stress fracture/reaction, the site coordinator will be notified automatically and the subject

will be asked to return for a second running analysis once the fracture has healed and they are cleared to run by their physician. The structural and biomechanical factors leading up to a tibial stress fracture will be assessed. In addition, comparisons will be made of mechanics before and after the stress fracture to determine whether subjects revert to their pre-injury mechanics. If relationships between mechanics and injury are established, future interventions including gait retraining should be explored.

Statement of Work

Between the two data collection sites, the following objectives were outlined in the approved Statement of Work for the third year. These objectives included:

1. Recruitment of the final 75 subjects per site for a total of 200 subjects per site.
2. Data recollected on those who have sustained a tibial stress fracture since the onset of the study.
3. Data analysis of two groups of subjects (those with and without a history of tibial stress fracture) started.
4. Two manuscripts submitted to peer-reviewed journals regarding the initial mechanical and structural comparisons between normals and subjects with previous tibial stress fractures.
5. Continue with follow-up procedures on subjects.

Adherence to Work Objectives

1) Recruitment of Subjects

To date, data have been collected on a total of 277 subjects: 162 at the University of Delaware and 115 at the University of Massachusetts. In the last year, 67 subjects have been collected in Delaware and 65 in Massachusetts. The target for the year was 75 at each location. Recruitment at the University of Delaware is slightly below target this year. This is due to a change in personnel: the original post-doctoral research fellow coordinating the project reached the end of their two year contract and subject recruitment and data collection was reduced during the changeover period to the new study coordinator. The new post-doctoral research fellow is now fully trained in all aspects of the project and recruitment and data collection have returned to normal levels.

This year subject recruitment and data collection at the University of Massachusetts has been the most successful yet. Data have been collected from 65 subjects, compared to 27 last year and 23 the year before. Although a great improvement on previous years, this is also slightly below the target for this year. This is due to the graduation of one of the doctoral students who was coordinating the project at the University of Massachusetts. A new doctoral student has been recruited, and will start working on the project in September 2003. Once this new member of the team is in post, subject recruitment and data collection will return to the high level that has been maintained for most of the last year.

According to the Statement of Work, all 400 subjects would be recruited by the third anniversary of the project. However, due to a delay in website development at the outset of the study, data collection did not get underway until September 1 2000. As a result of the delays in subject recruitment in year one, the University of Delaware has an additional 30 subjects to recruit over and above the target for the year and the University of Massachusetts has an additional 75 subjects outstanding. Various measures are being taken to increase recruitment in order to reduce this carried over deficit by the end of 2003. Specifically, the influx of new student athletes at the beginning of the Fall semester is an excellent opportunity to recruit large numbers of subjects in a short period of time. Over the last three years, good relationships have been established and maintained with women's cross country and track coaches working with University teams. In addition, several local road races that take place in the Fall have been identified. A booth at these events has proven to be an effective recruitment tool in the past. We continue to advertise the study on notice boards in local running shops and around campus (see Appendix 2 for flyer).

In order to enable the full 400 subjects to be recruited into the study, it may be necessary to extend the recruitment and data collection period by six months/ one year. This would extend the duration of the entire study by a similar amount, as each subject is followed up for a period of two years after initial data collection. If this is the case, we will either follow the last group for one year or request a no-cost year extension for an additional year, depending on which action the funding agency prefers.

2) Collection of Data on those who have sustained a tibial stress fracture

To date, tibial stress fractures have been recorded prospectively in three subjects. In addition, there have been two occurrences of tibial stress reaction, the precursor to tibial stress fracture. Of the three subjects that have sustained a tibial stress fracture, one is injured currently and two have returned to the laboratory following their return to full training for a post-injury gait reassessment. The data from these two individuals are presented in the Reportable Outcomes section as case studies to provide an initial indication of whether there are changes in running mechanics following recovery from a tibial stress fracture.

The data from the combined group that has sustained either a tibial stress fracture or reaction prospectively are also included in the Reportable Outcomes section in a comparison with a matched control group of subjects who have not sustained a fracture.

The low number of tibial stress fractures that have occurred during the study may be related to the high percentage of subjects in the 30 to 45 year age group (43%). Subjects in this age group who have been running for many years and never sustained a stress fracture are less likely to do so in the next two years. Therefore, we are now concentrating our recruitment efforts on the 18 to 30 year age group with the aim of

enrolling more subjects who may be susceptible to a stress fracture during the study period.

3) Data analysis of two groups of subjects (those with and without a history of tibial stress fracture)

To date, 21 subjects have entered the study with a history of previous tibial stress fracture. The results of the initial comparison of these data with matched subjects who do not have a history of tibial stress fracture are presented in the Reportable Outcomes section. These results form the basis of a manuscript about the lower extremity mechanics of female runners after tibial stress fracture that is currently in preparation.

No data have been eliminated from the study to date as a result of technical problems associated with data collection or reduction.

Manuscript submission

Two articles are in preparation for submission to peer-reviewed journals for publication. The first of these has the provisional title "Lower extremity mechanics of female runners following tibial stress fracture" and will be submitted to *Journal of Biomechanics* by the end of 2003. The second article is being developed from an abstract presented at the American College of Sports Medicine National Meeting this year and is provisionally titled "Prospective biomechanical investigation of iliotibial band syndrome in competitive female runners". It will be submitted to *Medicine and Science in Sport and Exercise* by the end of 2003.

Abstract Submission

In the past year, three additional abstracts have been submitted and were accepted for presentation. These abstracts were presented at the American College of Sports Medicine National Meeting in San Francisco, California, the XIXth International Society of Biomechanics Congress in Dunedin, New Zealand and the American Society of Biomechanics Annual Meeting in Toledo, Ohio. The references and a summary of these findings are provided in the Reportable Outcomes section and the complete abstracts are included in Appendix A.

5) Follow-up procedures

Subjects have been tracking their monthly running exposure and injuries since their initial visit and these data have been input into the database. The database continues to function properly and subjects have been logging in on a monthly basis to record their mileage and injuries. A summary of the injuries reported has been summarized in the Reportable Outcomes section.

The compliance rate for the follow up part of the study is high, and stands currently at 80%. A dropout was defined as a subject not having entered a monthly report into the website for 12 or more consecutive months. Subjects who have not responded to the

monthly email request for their running data for a shorter period are being contacted by telephone to obtain backdated monthly information. To date, a total of 18 subjects have now dropped out of the study. In addition, three subjects that have stopped running have withdrawn from the study: one due to pregnancy, one due to a bicycle accident and the third due to work pressures. This has resulted in an overall attrition rate of 6%. This is very low for a follow up study of this duration, and not a cause for concern.

The compliance and attrition rate this year compare favorably with the 78% compliance rate and 3% attrition rate (three dropouts and one withdrawal) for 2002. The slight improvement in compliance is encouraging as more subjects have now been enrolled in the study for longer. It should be noted that the compliance rate reported last year's was 96%. This was due to a calculation error in compliance for the year to 20 July 2002.

The calculation method employed originally, and used to calculate the compliance rate reported in 2002, simply took the total number of responses and divided it by the total number of requests for data. This resulted in an overestimate of the actual compliance rate because it included those additional months before the website went online and erroneous repeat entries, giving some subjects an apparent compliance rate of greater than 100%. These artificially high compliance rates for a few subjects resulted in an inflated mean compliance rate for the study.

Currently, compliance rate is calculated as the number of monthly responses submitted by a subject being divided by the number of monthly requests for data. Additional entries that were received from some of the early recruits to the project, backdating their records to the months before the website was online, are not included. Furthermore, any erroneous double submissions of the same data were excluded from the total number of submitted entries for an individual. It was felt that this rigorous method provides the best indication of compliance rate during follow up.

The review of last year's Annual Report suggested that the self-report injury information collection forms on the website may contain items that are hard for the participants to judge due to anatomical and medical terms being used. If self diagnosed initially, subjects are encouraged to report their injuries after they have been diagnosed by a medical professional. Only 53 of 226 (23%) prospective injuries reported to date were diagnosed or treated by someone other than a medical professional.

Subjects are encouraged to contact us if there is a question regarding their injury. They are also provided a space for comment on the online form regarding their injury. When any injuries related to the anterior lower leg are reported a clinician on the project will follow up with a telephone call. Therefore, we are able to further confirm the diagnosis. Any reported tibial stress fractures must be confirmed by x-rays, bone scans or MRIs. Tibial stress reactions have been operationally defined as pain specifically along the distribution of the tibia that is worsened with impact loading and relieved with rest. There is indication in the literature (Fredericson et al., 1995) that these stress reactions are the early stage of a stress fracture.

KEY RESEARCH ACCOMPLISHMENTS

The main focus of this study is the elucidation of the relationships between lower extremity structure, mechanics and the occurrence of tibial stress fractures. However, the large database of biomechanical, training and injury data that is being compiled during the study is proving to be a valuable source of information relating to other running injuries. To date, four abstracts that have been presented at various national and international conferences about the incidence of lower extremity stress fractures and their relationship to kinematic, kinetic and structural variables, the main thrust of the study. Additionally, a further three abstracts concerning the relationships between lower extremity mechanics and three common running injuries: iliotibial band friction syndrome, plantar fasciitis and patellofemoral pain syndrome have been presented.

At completion, the database generated from the 400 runners enrolled into this study will be a very comprehensive record of the biomechanics of female runners, their injury history and prospective injuries over a two year period. This will prove to be an invaluable resource not only in relation to stress fractures, but the many other injuries that are common in runners and result in time lost from training.

REPORTABLE OUTCOMES

This section contains all of the Reportable Outcomes to date:

- 1) Retrospective tibial stress fracture data for the manuscript that is in preparation for submission by the end of 2003
- 2) A summary of the prospective tibial stress fracture and tibial stress reaction data
- 3) A summary of all the lower extremity prospective stress fracture data
- 4) A summary of the pre and post injury data from the two prospective tibial stress fractures that have returned for a second assessment following recover from injury
- 5) Details of the three abstracts presented on overuse injuries
- 6) Other presentations made
- 7) A summary of the information recorded in the database.
- 8) A summary of degrees obtained that are supported by this award
- 9) A summary of employment and research opportunities applied for and received based on experience and training supported by this award

1) Summary of data on female runners who had sustained a tibial stress fracture previously

Aim 1: Determine whether differences in structure and mechanics exist between subjects with a prior tibial stress fracture to those who have not sustained a fracture.

At present, tibial stress fractures have been reported in 21 subjects. This group (RTSF) was matched with 17 control subjects (CON), who have never sustained any stress fractures, to enable a preliminary assessment of the lower extremity structural and functional differences between the two groups. The groups were matched for monthly running mileage and age, to remove the influence of these potentially confounding factors (Table 1).

Table 1: Mean (\pm standard deviation) monthly running mileage and age of the TSF and CON groups

	Mileage (miles/ month)	Age (years)
TSF (n=21)	116 \pm 38	32 \pm 11
CON (n=17)	109 \pm 27	31 \pm 12

Ground reaction force (GRF), kinematic data, and tibial acceleration data were recorded and averaged from 5 running trials. Three radiographs of the distal lower extremity were used to calculate the tibial area moment of inertia (Milgrom et al., 1989). Each subject underwent a structural evaluation by an experienced physical therapist.

Hypothesis 1.1: Runners who had sustained a previous TSF would exhibit differences in kinetic variables including increased instantaneous and average vertical loading rates, peak vertical and braking forces and stiffness compared to controls.

Subjects who had sustained a previous tibial stress fracture exhibited significantly greater instantaneous vertical loading rate (Fig. 1). Although not significant, a trend towards a higher average loading rate in the RTSF group compared to controls was also observed (Fig. 2). These results are in contrast to Crossley et al. (1999) who reported no differences in ground reaction force variables between RTSF and healthy runners. However, these authors used male runners who may exhibit differences in running mechanics compared to women runners (e.g. Ferber et al., 2003). No differences in peak vertical and braking forces or stiffness were observed between the two groups (Table 2).

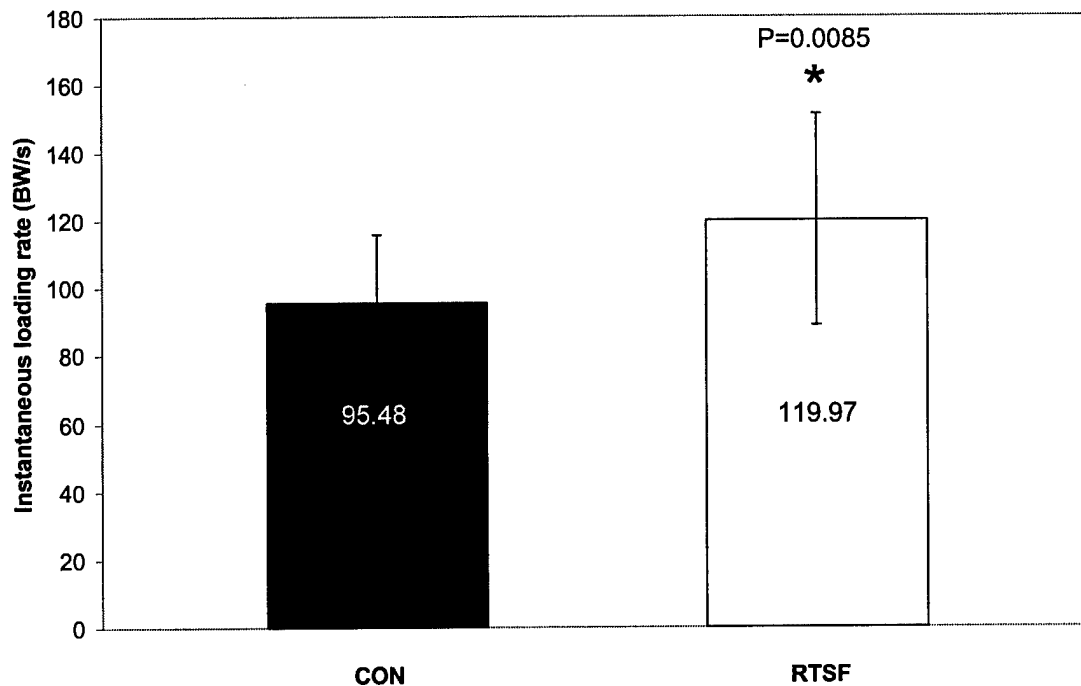


Figure 1: Instantaneous loading rate in subjects who had a previous tibial stress fracture versus healthy controls (* = significantly greater than controls).

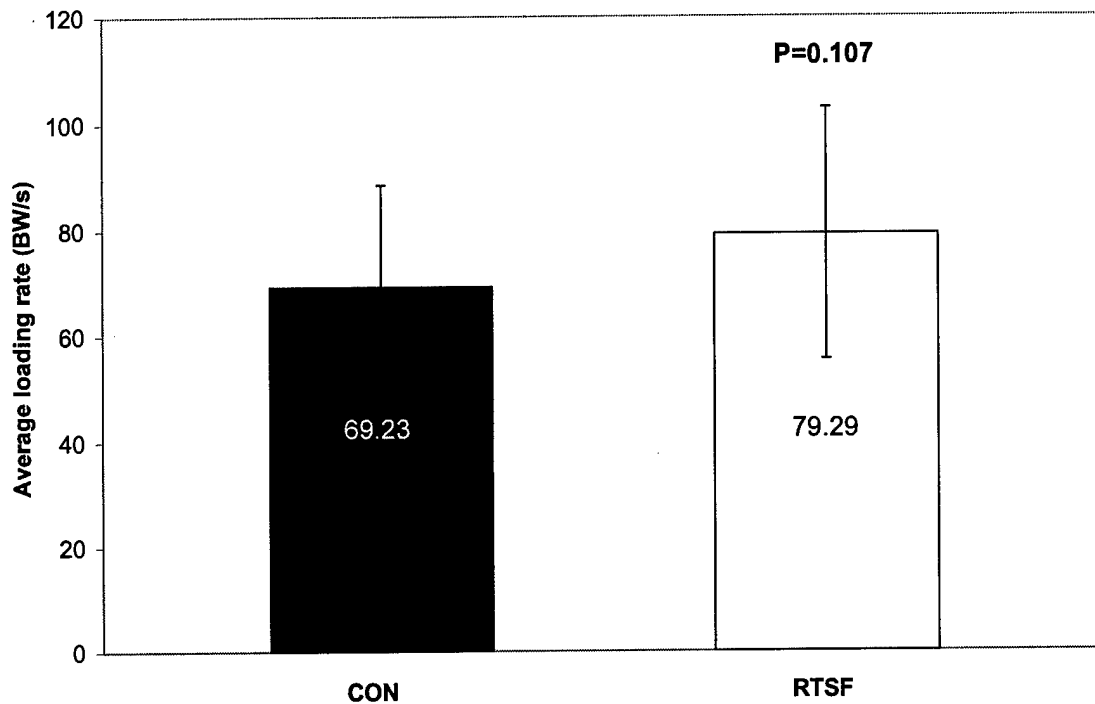


Figure 2: Average vertical loading rate in subjects who had a previous tibial stress fracture versus healthy controls.

Hypothesis 1.2: Runners who had sustained a previous TSF would exhibit differences in kinematic variables including increased peak positive tibial acceleration, decreased ankle dorsiflexion excursion and decreased knee flexion excursion compared to controls.

Subjects who had sustained a tibial stress fracture previously exhibited significantly greater peak positive tibial acceleration than control subjects, in addition to a reduced knee flexion excursion (knee flexion range of motion from foot strike to peak knee flexion during the stance phase) (Fig. 3 and 4). There was no difference in ankle dorsiflexion excursion between the two groups. Knee joint excursion was reduced in the TSF group, but these changes did not result in an increase in overall stiffness in these runners. A “stiff” runner will spend less time in contact with the ground (Farley and Gonzalez, 1996) and will attenuate less shock between the leg and the head (McMahon et al., 1987). The results obtained so far do not indicate a relationship between vertical stiffness and the incidence of tibial stress fracture. This is in contrast to the finding of Farley and Gonzalez (1996) who suggested lower extremity stiffness and knee flexion excursion are highly correlated and may lead to stress fracture.

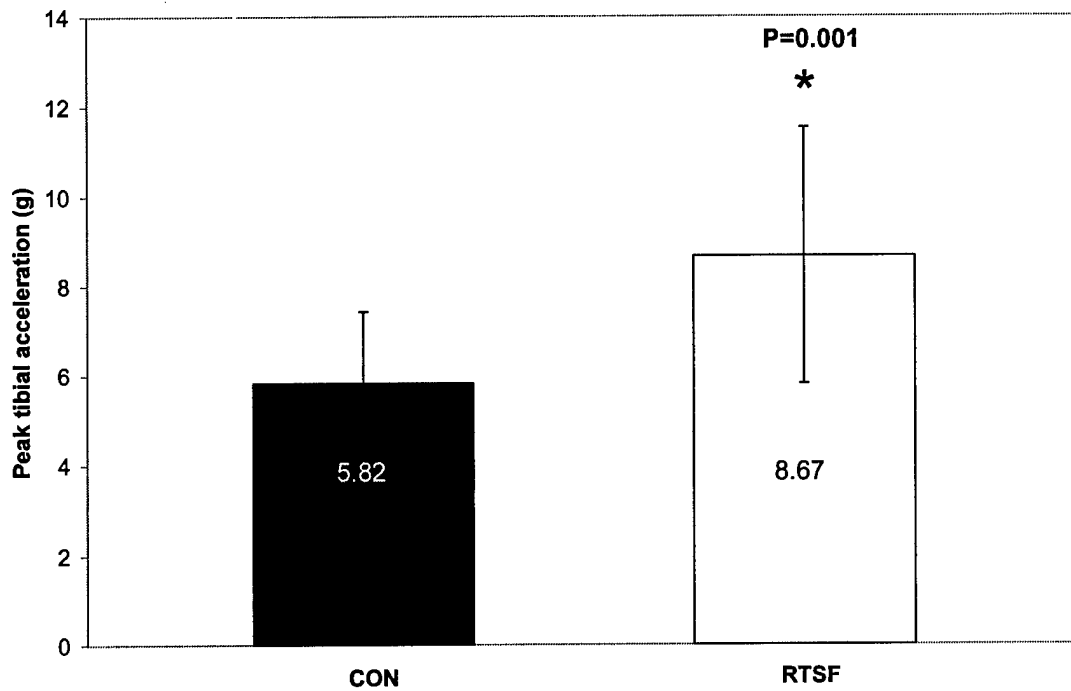


Figure 3: Peak positive tibial acceleration in subjects who had a previous tibial stress fracture versus healthy controls (* = significantly greater than controls).

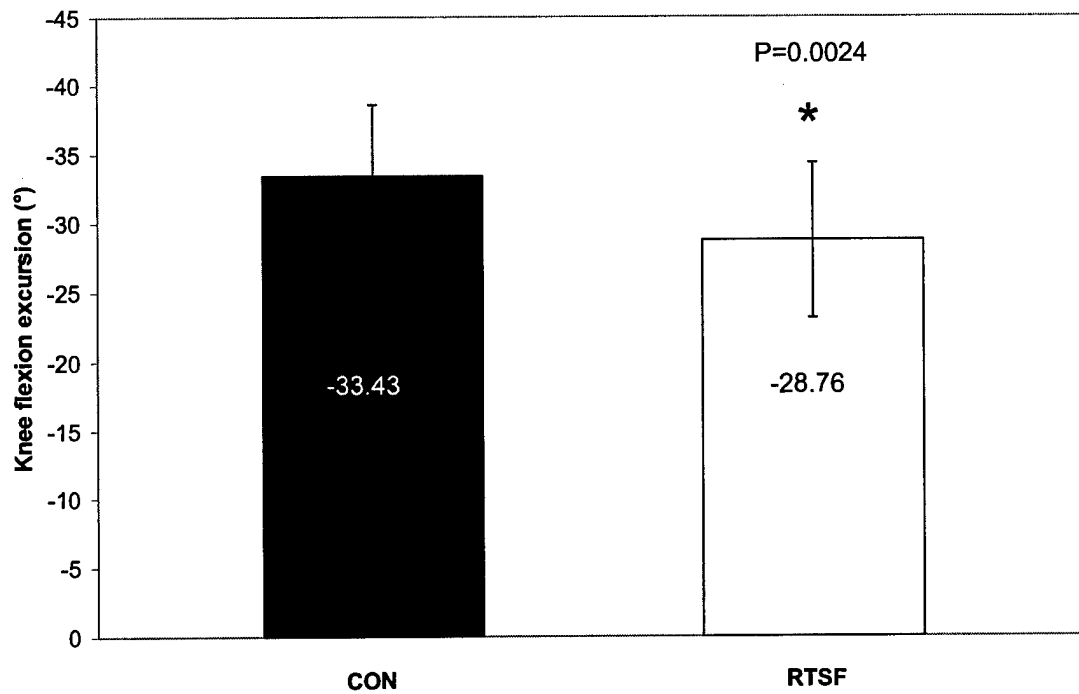


Figure 4: Knee flexion excursion in subjects who had a previous tibial stress fracture versus healthy controls (* = significantly less than controls).

Hypothesis 1.3: Runners who had sustained a previous TSF would exhibit differences in structural variables including increased tibial varum and decreased tibial area moment of inertia compared to healthy controls.

Although specific structural characteristics have been associated with stress fracture injuries (Crossley et al., 1999; Milgrom et al., 1989), these groups of female distance runners did not demonstrate this relationship. However, the RTSF group exhibited 15% greater tibial varum compared with the control group (Fig. 5). No difference tibial area moment of inertia was observed between the two groups (Table 2).

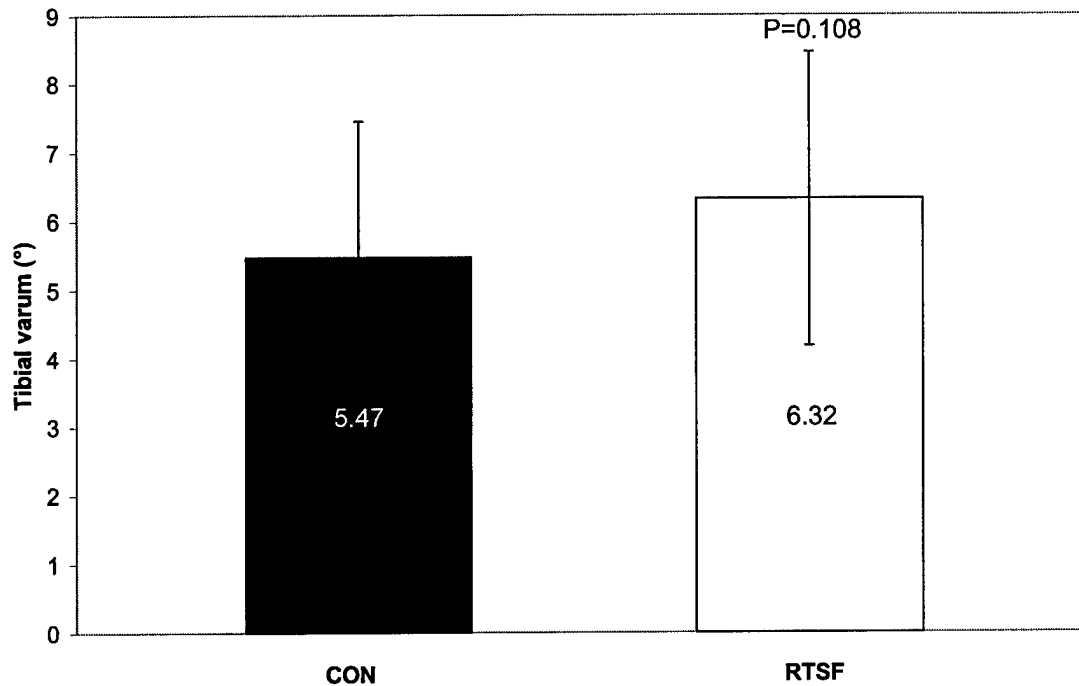


Figure 5: Tibial varum in subjects who had a previous tibial stress fracture versus healthy controls.

Table 2: Variables that showed no difference between subjects who had a previous tibial stress fracture and healthy controls.

	RTSF	CON	P value
Ankle dorsiflexion excursion	18.96 ± 5.35	20.46 ± 3.53	0.16
Peak braking force (BW)	-0.39 ± 0.05	-0.37 ± 0.05	0.12
Peak vertical force (BW)	2.57 ± 0.18	2.54 ± 0.17	0.29
Stiffness (kN/m)	9.31 ± 1.71	9.17 ± 1.12	0.40
Area moment of inertia (mm ⁴)	13383 ± 3379	13184 ± 3788	0.45

The observed decreases in knee and ankle joint excursion suggest that stiffness would be increased in the RTSF group. However, this was not supported by the global measure of vertical stiffness included in this analysis. Future analyses of these data will include assessment of the stiffness of the individual joints, which may be more informative than the simple global measure employed here. The observed increases in vertical loading rate and tibial acceleration support the notion that these impact-related kinetic variables may be related to the risk of tibial stress fracture.

There were no differences in tibial area moment of inertia between the RTSF and control groups. This is contrary to the study by Milgrom et al. (1989) of male infantry recruits that found a highly significant reduction in tibial area moment of inertia in the recruits who sustained a tibial stress fracture. The lack of a significant difference between the RTSF and control groups in this preliminary analysis suggests that other factors may be important in the etiology of tibial stress fractures in the female running population. Overall, area moment of inertia values in the RTSF group were 20% less than those reported by Milgrom et al. (1989). However, this is due to the smaller tibial width of females, which is correlated strongly with tibial area moment of inertia.

However, prospective studies are essential to determine whether the observed changes in these kinematic and kinetic variables were present prior to the stress fracture injury. Furthermore, there may be numerous underlying mechanisms associated with stress fracture injuries that are difficult to account for in a retrospective study. Potential underlying mechanisms in addition to training mileage and age may include training surface, number of speed sessions per month, nutrition and history of amenorrhea. Nevertheless, based on the data from these 20 subjects, several of the hypotheses related to the occurrence of tibial stress fractures were supported.

It should be noted that the kinetic differences between the TSF and CON groups are similar to those reported for the smaller group ($n=10$) of subjects that was considered last year. The group studied in the 2002 report was more diverse than the present group and included subjects who had sustained any type of lower extremity stress fracture. However, there are differences between the groups in the significance of kinematic and structural variables. This may indicate that some variables are indicative of a global risk of lower extremity stress fracture, whereas others are specific to stress fracture of a particular bone. Or the differences may simply be related to the relatively small number of subjects studied previously. As more subjects are recruited into the study and the power of the statistical analysis is increased, the pattern of differences between those subjects that have and have not sustained a tibial, or other, stress fracture may become clearer.

2) Summary of the prospective data obtained on female runners who sustained a tibial stress fracture or tibial stress reaction during the study

Aim 2: Determine whether differences in structure and mechanics exist between subjects who sustain a tibial stress fracture or reaction (PTSF) to those who do not sustain a fracture.

Currently, only a relatively small number of participants have experienced tibial stress fractures (3) or tibial stress reactions (2) during the follow-up period of the study. Due to the small number of participants who have experienced a tibial stress fracture, those that have experienced a tibial stress reaction (TSR) are also included in this analysis. Since TSR has been shown to be the precursor of TSF, we felt it was appropriate to include these. A participant in the study who manages her injuries promptly and appropriately is less likely to experience the progression from TSR to TSF. Therefore inclusion of the TSR group enables the mechanics of susceptible individuals to be determined and compared to healthy controls. The PTSF group was compared to a control group that was matched for monthly running mileage and age (Table 3).

Table 3: Mean (\pm standard deviation) monthly running mileage and age of the PTSF and CON groups

	Mileage (miles/ month)	Age (years)
PTSF (n=5)	74 \pm 26	25 \pm 5
CON (n=5)	78 \pm 19	28 \pm 8

Hypothesis 2.1: Runners who sustained a TSF or TSR would exhibit differences in kinetic variables including increased instantaneous and average vertical loading rates, peak vertical and braking forces and stiffness compared to controls.

Subjects who sustained a tibial stress fracture (or reaction) during the study exhibited a significantly greater instantaneous vertical loading rate. PTSF subjects also exhibited a trend towards increased average loading rate ($P=0.059$). While not significant, a 40% in average vertical loading rate compared to control subjects was noted (Fig. 6 & 7). No difference in stiffness was found between the prospective TSF group and the healthy controls (Table 4). These preliminary results from the TSFs sustained during the study generally follow the patterns highlighted by the comparison of the mechanics of subjects who had sustained a TSF previously with healthy controls. That is, both prospective and retrospective TSF subjects show increases in loading rates.

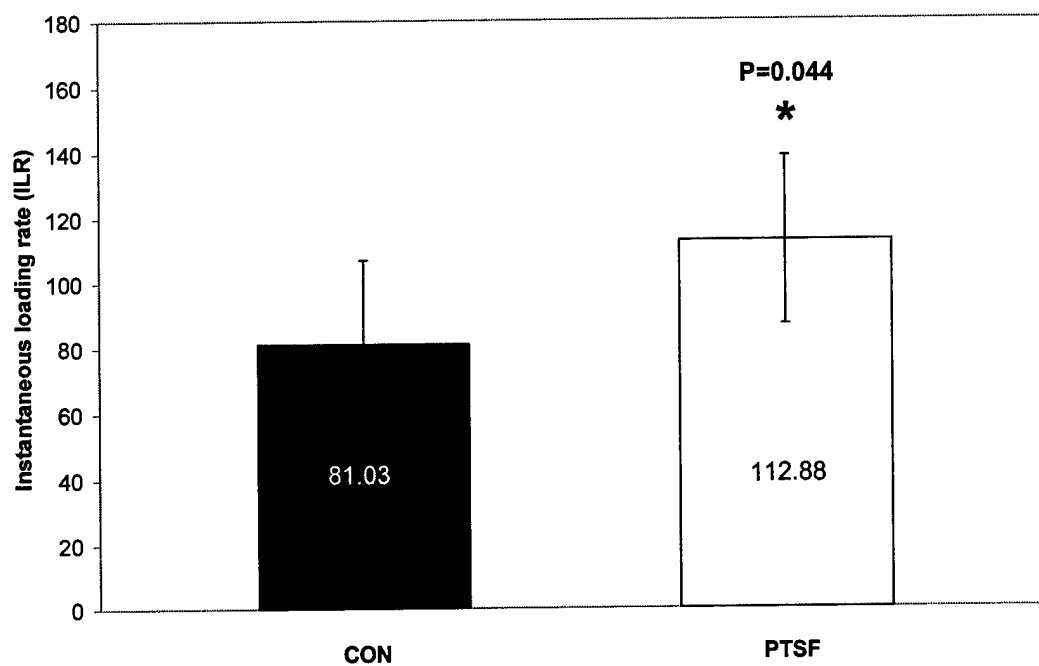


Figure 6: Instantaneous loading rate in subjects who developed a tibial stress fracture versus healthy controls (* = significantly less than controls).

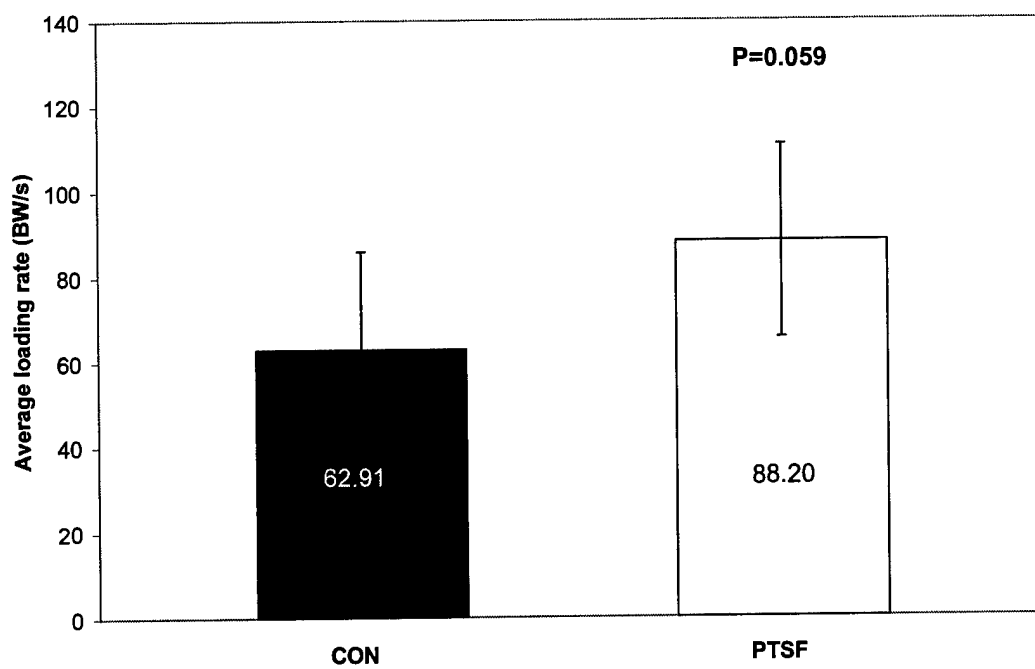


Figure 7: Average loading rate in subjects who developed a tibial stress fracture versus healthy controls.

Hypothesis 2.2: Runners who sustained a PTSF would exhibit differences in kinematic variables including increased peak positive tibial acceleration, decreased ankle dorsiflexion excursion and decreased knee flexion excursion compared to controls.

A trend towards a greater peak positive tibial acceleration was noted in the PTSF group. While not a significant difference, this represents nearly a twofold increase (Fig. 8). This variable was also significantly increased in the RTSF group. No differences in kinematic characteristics were found between the prospective TSF group and the healthy controls (Table 4). This differs from the retrospective TSF group, which had reduced knee flexion excursion and a trend towards reduced dorsiflexion excursion compared to the control group. The lack of significant findings in the presence of large differences in these subjects is likely due to the small subject numbers. As subjects are added the results may become significant.

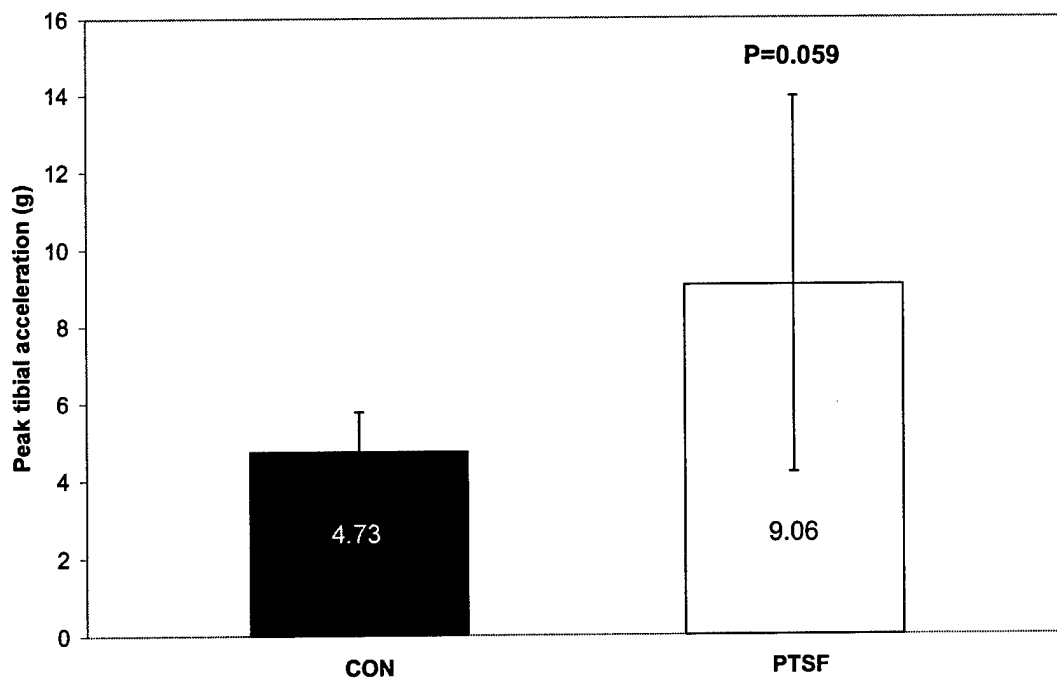


Figure 8: Peak positive tibial acceleration in subjects who developed a tibial stress fracture versus healthy controls.

Hypothesis 2.3: Runners who sustained a PTSF would exhibit differences in structural variables including increased tibial varum and decreased tibial area moment of inertia compared to healthy controls.

Although specific structural characteristics have been associated with stress fracture injuries (Crossley et al., 1999; Milgrom et al., 1989), these groups of female distance runners did not demonstrate this relationship. No differences in structural characteristics were found between the prospective TSF group and the healthy controls (Table 4). This is in agreement with the retrospective TSF group, which also showed no differences in structural measures between the injured and control groups.

Table 4: Variables that showed no difference between subjects who had a previous tibial stress fracture and healthy controls.

	PTSF	CON	P value
Peak braking force (BW)	0.38 ± 0.05	0.37 ± 0.05	0.47
Peak vertical force (BW)	2.55 ± 0.09	2.54 ± 0.17	0.15
Stiffness (kN/m)	9.21 ± 0.99	9.63 ± 1.43	0.30
Ankle dorsiflexion excursion (°)	20.62 ± 2.90	19.47 ± 2.73	0.27
Knee flexion excursion (°)	34.26 ± 4.57	35.73 ± 3.44	0.29
Tibial varum (°)	5.40 ± 0.89	6.00 ± 1.87	0.27
Area moment of inertia (mm ⁴)	12250 ± 869	13184 ± 3788	0.44

In conclusion, the limited amount of data so far available for prospective tibial stress fractures and tibial stress reactions indicate that changes in ground reaction force variables reflect those observed in the retrospective tibial stress fracture group. No differences were found in structural or kinematic data, although this may be a consequence of the small subject group.

The etiology of a TSF is multifactorial in nature but is related, in part, to some combination of lower extremity running mechanics, bone structure, peak forces and loading rates. Overall, these are encouraging results. As more subjects experience stress fractures, we hope to be able to develop a predictive model.

3) Summary of the prospective data obtained on all of the lower extremity stress fractures: comparison to uninjured female runners

Aim 3: Determine whether differences in structure and mechanics exist between subjects who sustain a tibial stress fracture or reaction (PTSF) to those who do not sustain a fracture.

Due to the small number of participants who have experienced a TSF or TSR, we also analysed all prospective stress fracture injuries combined (3 TSF, 2 TSR, 3 femoral, 1 pelvis, 1 metatarsal). While this increases the statistical power of the comparison to healthy controls, testing a more diverse group of injured runners (PSF) may mask any differences between the structural and mechanical factors associated with a stress fracture in a specific bone.

Table 5: Mean (\pm standard deviation) monthly running mileage and age of the PSF and CON groups

	Mileage (miles/ month)	Age (years)
PSF (n=10)	95 \pm 37	29 \pm 11
CON (n=10)	101 \pm 35	27 \pm 9

Hypothesis 3.1: Runners who sustained a PSF would exhibit differences in kinetic variables including increased instantaneous and average vertical loading rates, peak vertical and braking forces and stiffness compared to controls.

Subjects who sustained a PSF during the study exhibited a trend towards greater instantaneous (24%) and average (21%) vertical loading rates (Fig. 9 & 10). No difference in stiffness was found between the PSF group and the healthy controls (Table 6). These common trends found when all prospective lower extremity stress fractures are considered generally follow the patterns highlighted by the subjects who had sustained a TSF either during the study or previously. That is, both prospective and retrospective TSF subjects show increases in loading rates.

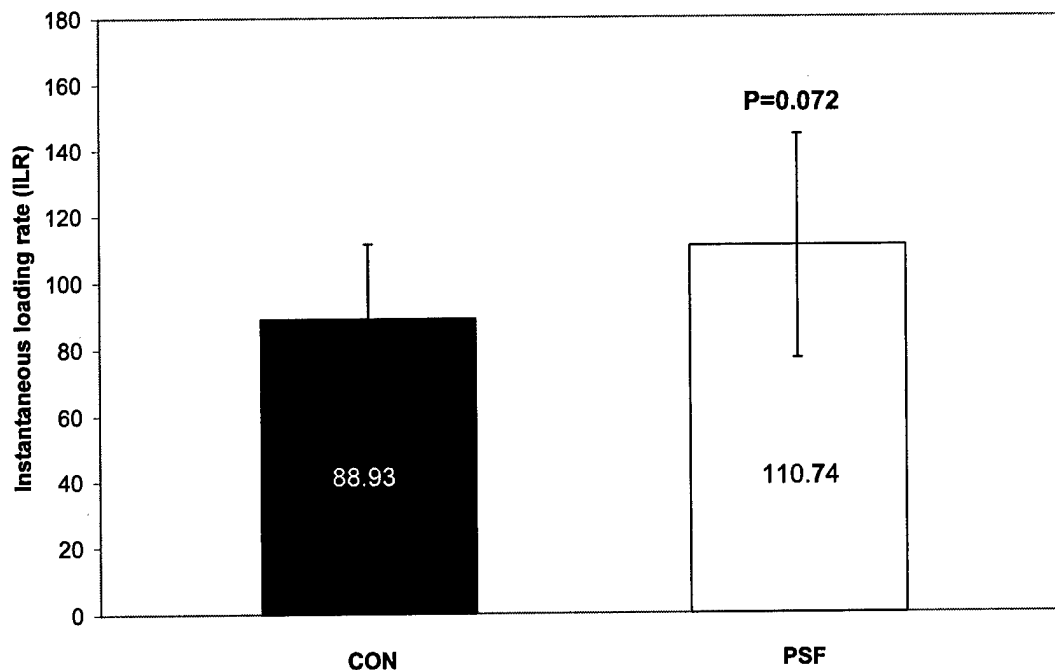


Figure 9: Instantaneous loading rate in subjects who developed a stress fracture versus healthy controls.

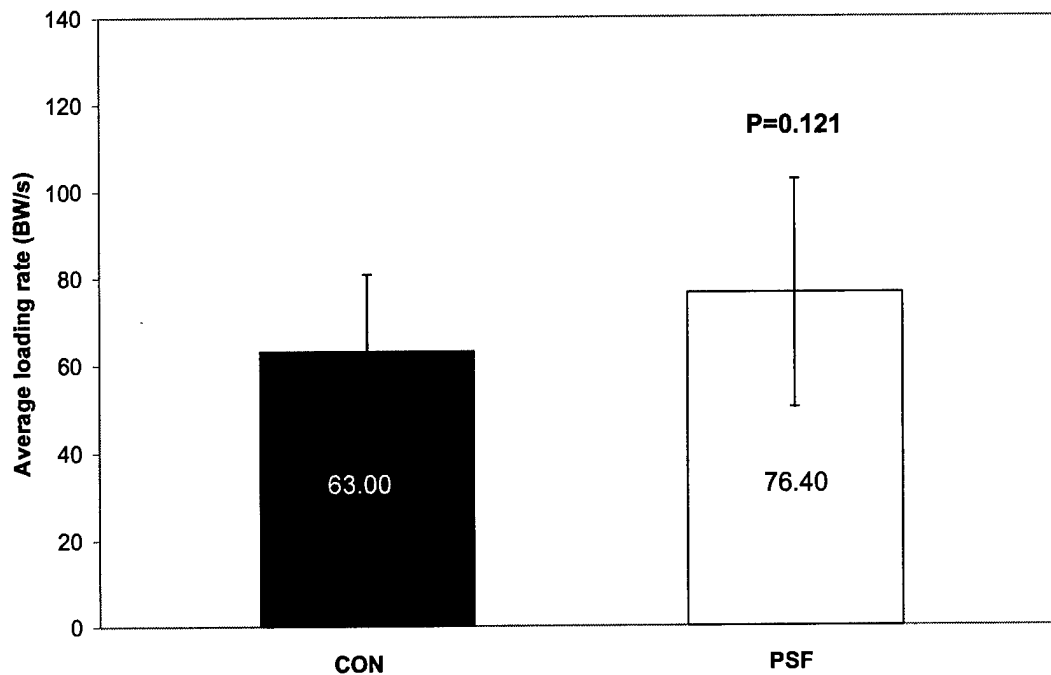


Figure 10: Average loading rate in subjects who developed a stress fracture versus healthy controls.

Hypothesis 3.2: Runners who sustained a PSF would exhibit differences in kinematic variables including increased peak positive tibial acceleration, decreased ankle dorsiflexion excursion and decreased knee flexion excursion compared to controls.

There was a significant increase in peak positive tibial acceleration between the two groups (Fig. 11). No differences in kinematic characteristics were found between the PSF group and the healthy controls (Table 6). This is in agreement with the PTSF group, but differs from the retrospective TSF group, which had reduced knee flexion excursion and a trend towards reduced dorsiflexion excursion compared to the control group.

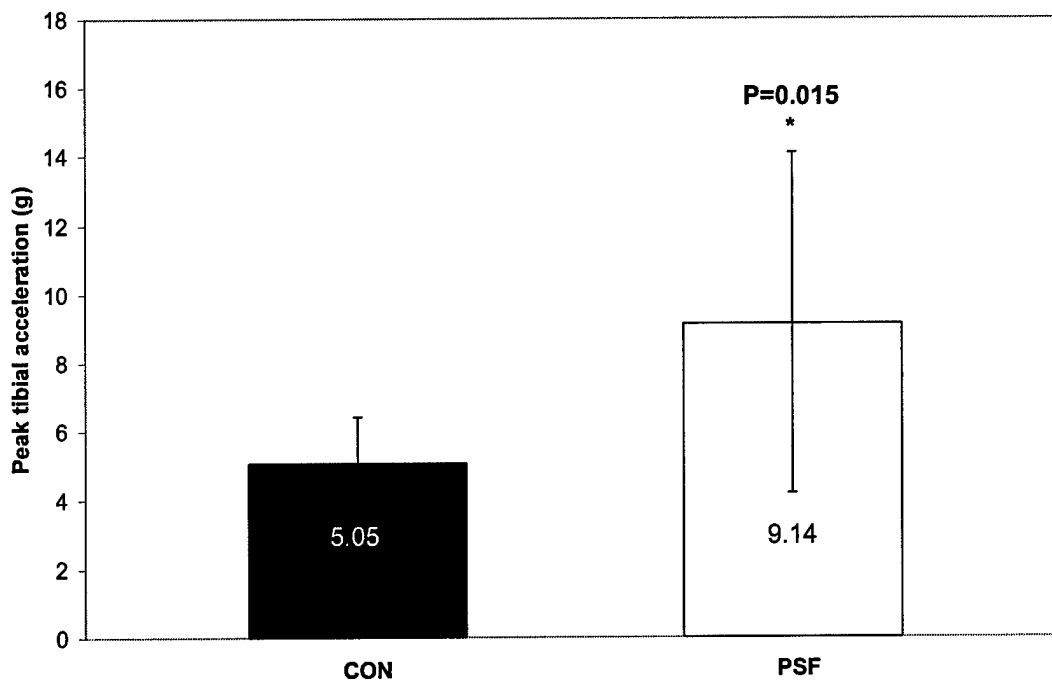


Figure 11: Peak positive tibial acceleration in subjects who developed a stress fracture versus healthy controls (* = significantly less than controls).

Hypothesis 3.3: Runners who sustained a PSF would exhibit differences in structural variables including increased tibial varum and decreased tibial area moment of inertia compared to healthy controls.

Although specific structural characteristics have been associated with stress fracture injuries (Crossley et al., 1999; Milgrom et al., 1989), these groups of female distance runners did not demonstrate this relationship. No differences in structural characteristics were found between the PSF group and the healthy controls (Table 6). This is in agreement with both the RTSF and PTSF groups, which also showed no differences in structural measures between the injured and control groups.

Table 6: Variables that showed no difference between subjects who had a previous stress fracture and healthy controls.

	PSF	CON	P value
Peak braking force (BW)	-0.37 ± 0.07	-0.38 ± 0.05	0.40
Peak vertical force (BW)	2.51 ± 0.17	2.63 ± 0.17	0.07
Stiffness (kN/m)	9.08 ± 1.03	9.26 ± 1.20	0.37
Ankle dorsiflexion excursion (°)	17.97 ± 6.45	20.45 ± 2.70	0.14
Knee flexion excursion (°)	-32.35 ± 4.66	-34.20 ± 5.02	0.20
Tibial varum (°)	5.56 ± 1.4	5.40 ± 2.41	0.43
Area moment of inertia (mm ⁴)	11912 ± 1067	12516 ± 2810	0.33

In conclusion, the limited amount of data so far available for all prospective lower extremity stress fractures reflects that observed in the prospective and retrospective tibial stress fracture groups.

4) Summary of pre and post injury data from the two prospective tibial stress fractures

Aim 4: Compare mechanics of individuals with healed tibial stress fractures to their mechanics prior to the fracture to determine whether compensation for injury occurs.

Hypothesis 4.1: Runners with healed TSFs would not exhibit changes in kinetic variables including instantaneous and average vertical loading rates, peak vertical and braking forces and stiffness compared to their pre-injury status.

Hypothesis 4.2: Runners with healed TSFs would not exhibit changes in kinematic variables including peak tibial acceleration, ankle dorsiflexion excursion and knee flexion excursion compared to their pre-injury status.

With the relatively small number of participants who have experienced tibial stress fractures prospectively and returned for a reassessment, statistical analyses of the preliminary results have not been performed. Results for each of these variables will be discussed for each individual with respect to trends observed in the data (Fig. 12 – 19).

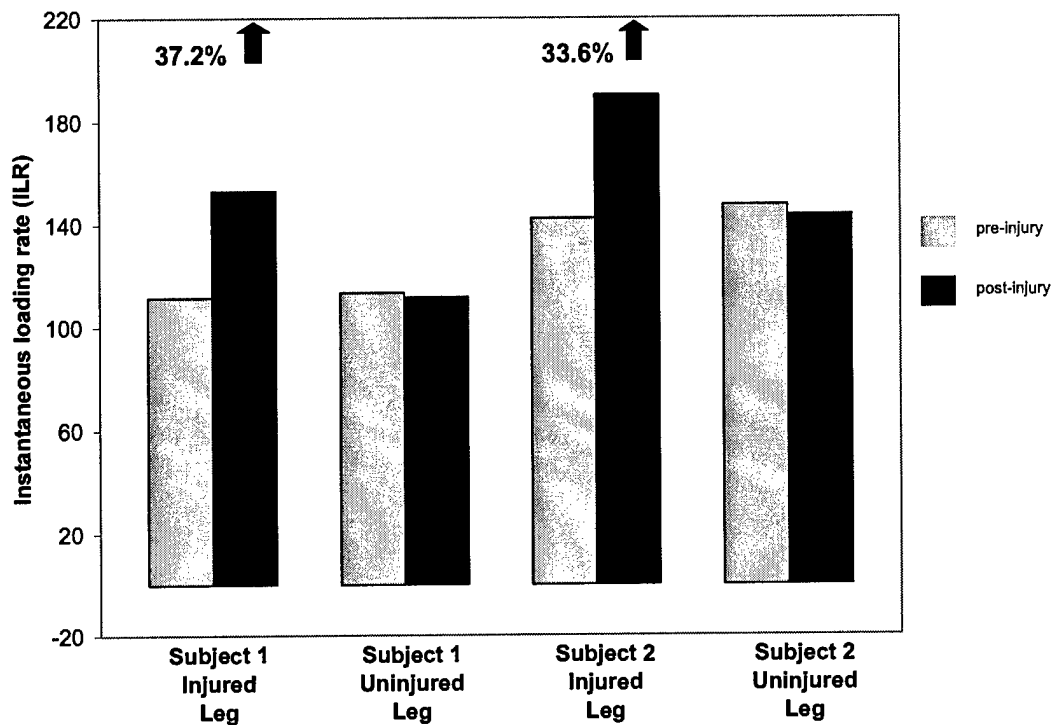


Figure 12: Instantaneous loading rate for the two prospective tibial stress fracture subjects pre and post injury.

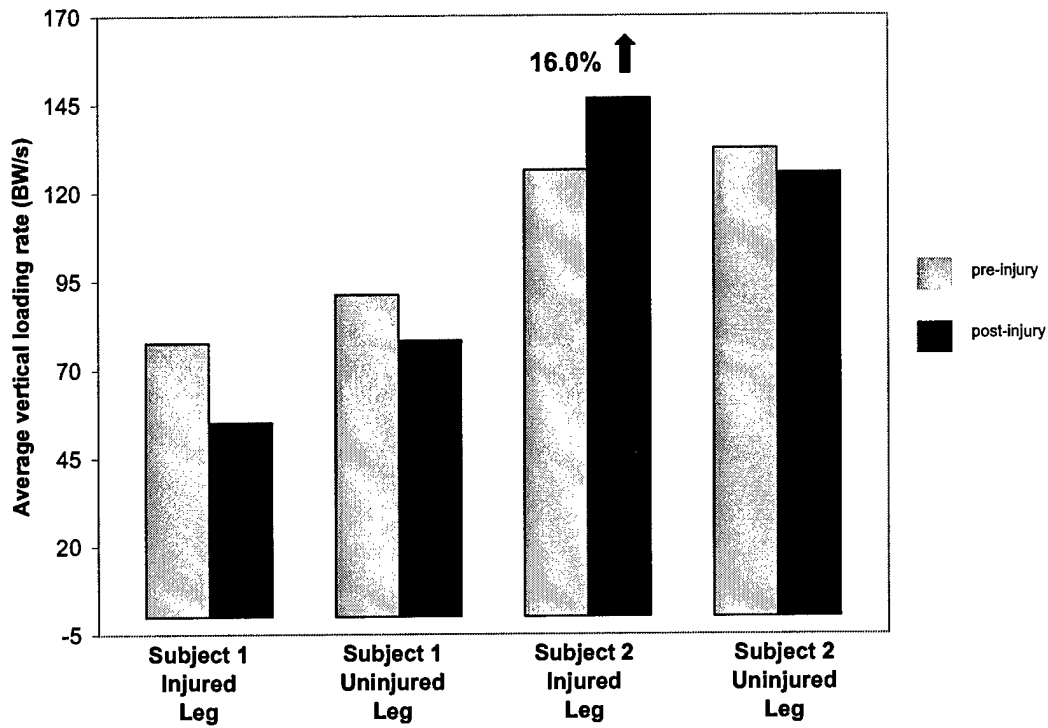


Figure 13: Average loading rate for the two prospective tibial stress fracture subjects pre and post injury.

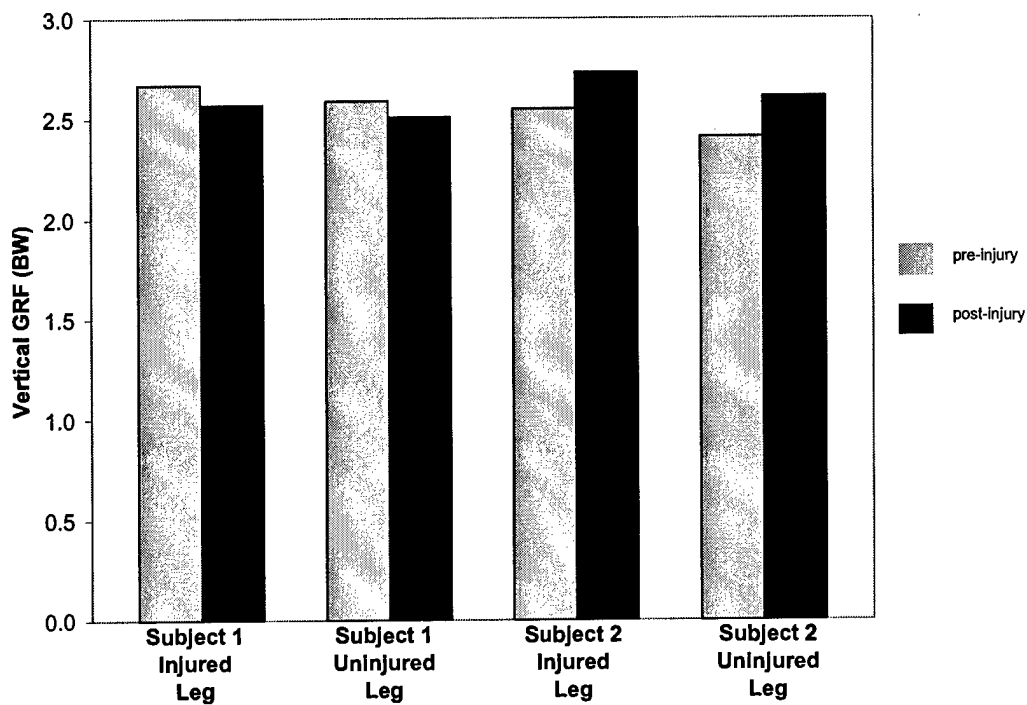


Figure 14: Peak vertical ground reaction force for the two prospective tibial stress fracture subjects pre and post injury.

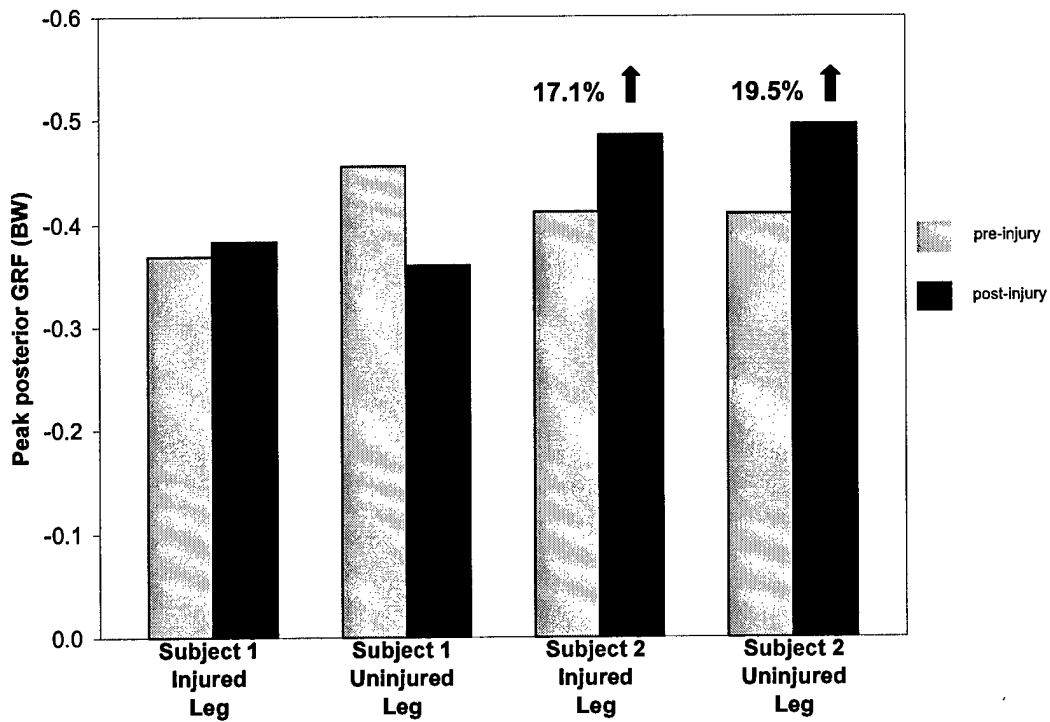


Figure 15: Peak braking force for the two prospective tibial stress fracture subjects pre and post injury.

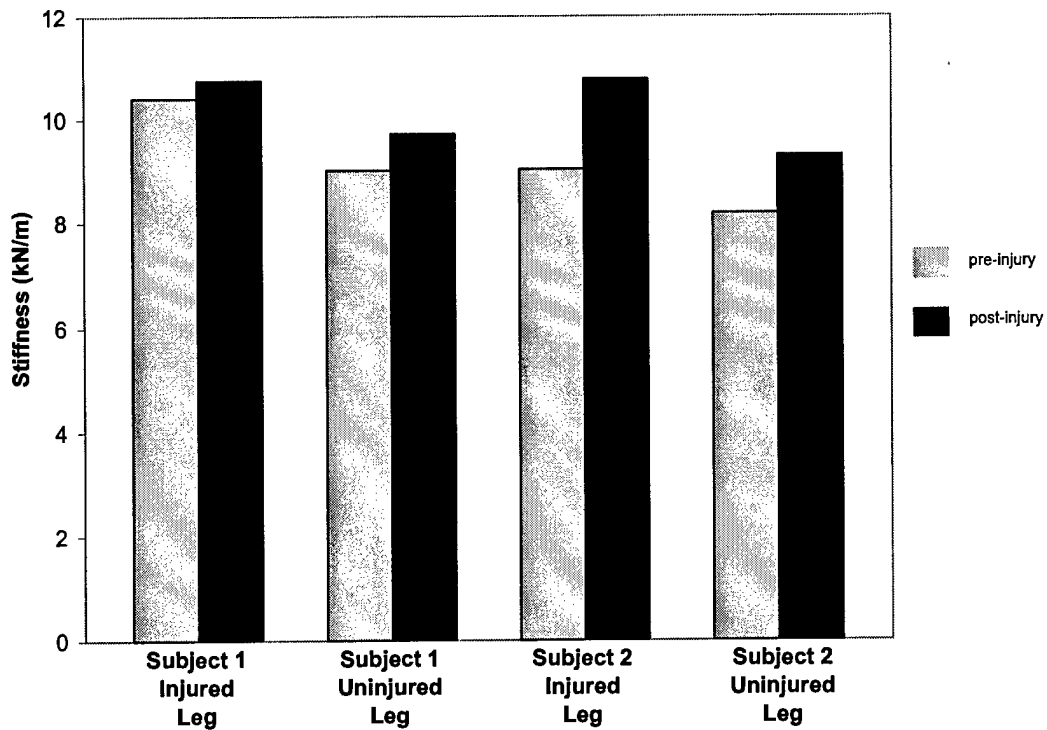


Figure 16: Lower extremity stiffness for the two prospective tibial stress fracture subjects pre and post injury.

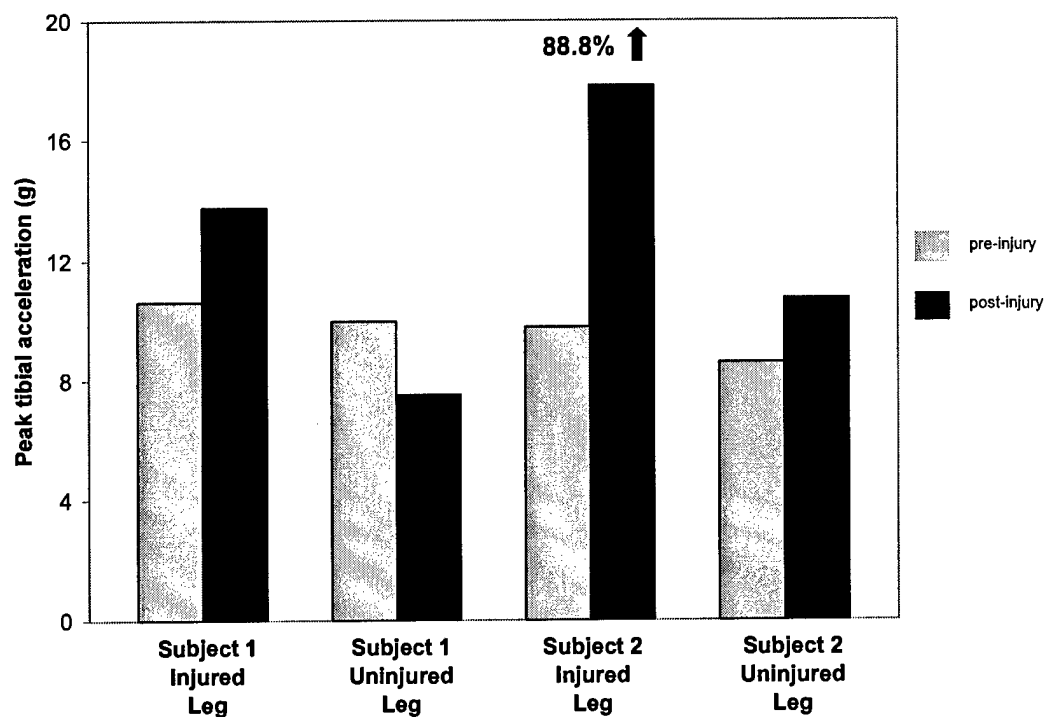


Figure 17: Peak positive tibial acceleration for the two prospective tibial stress fracture subjects pre and post injury.

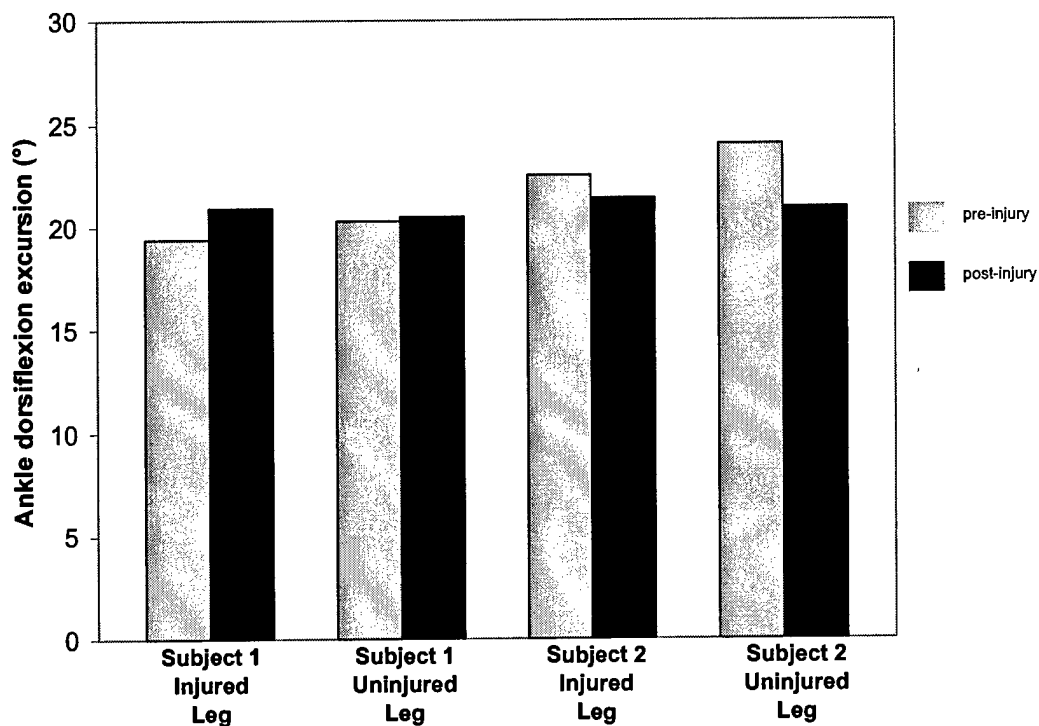


Figure 18: Ankle dorsiflexion excursion for the two prospective tibial stress fracture subjects pre and post injury.

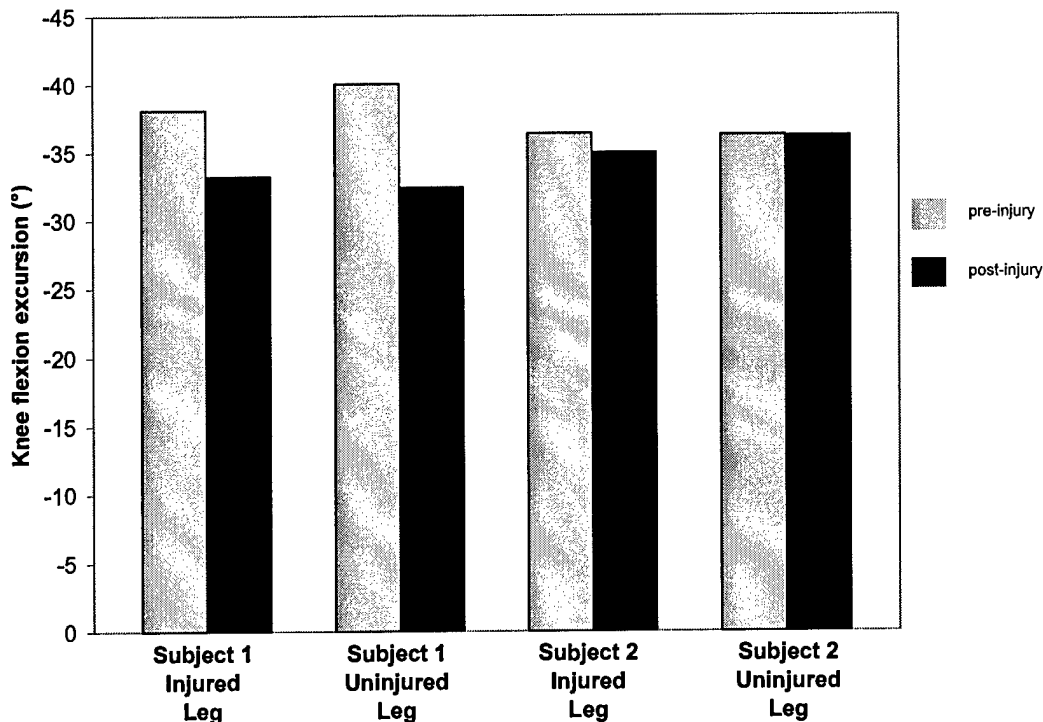


Figure 19: Knee flexion excursion for the two prospective tibial stress fracture subjects pre and post injury.

Generally, subject 1 shows some changes between their pre- and post- injury mechanics. Instantaneous loading rate and peak positive acceleration increased post injury on the injured side and knee flexion excursion decreased. This mirrors the differences observed between the RTSF and control group and is contrary to the hypothesis that there would be no change between pre and post injury status. However, this subject's data are confounded because the subject also had a tibial stress fracture prior to being enrolled into the study, and may have already changed their mechanics as a result of the previous fracture.

Subject 2 does not have this additional confounding factor, as she never had a tibial stress fracture prior to entering the study. This subject shows differences in her pre and post injury mechanics. Interestingly, these changes are such that the subject appears to be more at risk of injury as several key variables expected to increase stress on the lower extremities are increased. There is a general stiffening, perhaps guarding, of the lower extremity, suggested by the increase in peak vertical and braking ground reaction forces and increased stiffness. There is also an increase in instantaneous loading rate in the injured limb, as observed in subject 1. Another similarity with subject 1 is a large increase in peak positive tibial acceleration, which has also been implicated in risk of tibial stress fracture (Milgrom et al., 1989).

Since only two subjects have so far returned for a post-injury visit following tibial stress fracture, these data provide only a suggestion of the changes that may occur following recovery from a tibial stress fracture. As more tibial stress fractures occur in the study population, and return visits are made following recovery and return to full training, statistical analysis of the changes will be carried out to determine whether there is a change between pre and post tibial stress fracture mechanics.

If these findings are seen consistently as additional subjects are added, there may be a need to retrain their gait patterns to reduce the risk of recurring stress fractures. In addition, if differences between pre and post injury mechanics persist, this provides further support that prospective studies may be needed.

5) List of Publications

Since the last report, three additional abstracts have been submitted and were accepted for presentation. These abstracts were presented at the American College of Sports Medicine National Meeting in San Francisco, California, the XIXth International Society of Biomechanics Congress in Dunedin, New Zealand and the American Society of Biomechanics Annual Meeting in Toledo, Ohio. These abstracts are included in Appendix A and the references are provided below.

Ferber, R., McClay Davis, I., Hamill, J. & Pollard, C.D. (2003). Prospective biomechanical investigation of iliotibial band syndrome in competitive female runners. *Medicine and Science in Sports and Exercise*, **35**, S91.

McClay Davis, I., Ferber, R., Hamill, J. & Pollard, C.D. (2003). Rearfoot mechanics in competitive runners who had experienced plantar fasciitis. *Book of Abstracts 2003 XIXth International Society of Biomechanics Congress*, Dunedin, New Zealand.

McClay Davis, I., Dierks, T.A. Ferber, R. & Hamill, J. (2003). Lower extremity mechanics in patients with patellofemoral joint pain: a prospective study. *Book of Abstracts 2003 American Society of Biomechanics Annual Meeting*, Toledo, Ohio.

From the data collected during years 1 and 2, three abstracts were submitted and presented at the American College of Sports Medicine National Meeting in St Louis, Missouri and at the World Congress of Biomechanics in Calgary Alberta, Canada. The references are provided below.

McClay Davis, I., Ferber, R., Dierks, T.A., Butler, R.J., & Hamill, J. (2002). Variables associated with the incidence of lower extremity stress fractures. *Book of Abstracts 2002 World Congress of Biomechanics*, Calgary, Alberta, Canada.

Ferber, R., McClay Davis, I., Hamill, J., Pollard, C.D., & McKeown, K.A. (2002). Kinetic variables in subjects with previous lower extremity stress fractures. *Medicine and Science in Sports and Exercise*, **34**, s25.

Pollard, C.D., & McKeown, K.A. Hamill, J., Ferber, R., McClay Davis, I. (2002). Selected structural characteristics of female runners with and without lower extremity stress fractures. *Medicine and Science in Sports and Exercise*, **34**, s991.

From the data collected during year 1, one abstract was submitted and presented at the American Physical Therapists' Association Combined Sections Meeting in Boston, Massachusetts. The reference is provided below.

Multiple Lower Extremity Stress Fractures In A Division I Cross Country Runner: A Case Study. Pollard C.D., McClay I.S., Hamill J. 2001 APTA Combined Sections Meeting, Boston, Massachusetts.

6) Presentations made

In addition to the conference presentations associated with the abstracts detailed in section 3 above, the following presentation was made.

Gait Retraining in Runners: An Application of the VICON Real-Time System
Presentation made to the Vicon Users' Group Meeting at the Gait and Clinical Movement Analysis Annual Meeting 2003, Wilmington DE, Thursday May 8th, 2003.

7) Summary of information from the database

A summary of all the retrospective and prospective injury information we have collected is presented in tables 6 and 7. It is interesting to note the relatively large number of retrospective stress fractures compared with the other lower extremity injuries. Typically, the knee is the most common site of running injuries, with patellofemoral pain being the most common single injury at the knee. In this study, the lower leg is the most common site of injury and tibial stress fractures are the most common single injury at this site. We feel this is because we initially advertised this study as a stress fracture study and not as a running injury study. We have since changed this advertising strategy.

In the prospective data, the injury pattern is more typical, with the knee being the most common site of injury and patellofemoral pain the second most common knee injury. Furthermore, the incidence of tibial stress fractures and tibial stress reaction is much reduced in the prospective database.

Table 7: Summary of retrospective injury information collected from the website database.

Injury Category		Incidence of Injury
Back	TOTAL	32
Back sprain		2
Back strain		14
Disc pathology		1
Back other		15
Hip/ groin	TOTAL	32
Gluteal strain/ tendinitis		1
Greater trochanteritis		6
Groin strain/ tendinitis		1
Hip/ groin injury other		19
Pelvic stress fracture		5
Thigh	TOTAL	27
Femoral stress fracture		7
Hamstring strain		8
Quadriceps strain		4
Thigh other		8
Knee	TOTAL	79
IT band friction syndrome		28
Lateral collateral strain		1
Medial collateral strain		1

Medial plica syndrome	1
Patellar tendinitis	7
Patellofemoral pain syndrome	16
Pes Anserinus tendinitis	1
Knee other	24
Lower leg	TOTAL 127
Achilles tendinitis	19
Acute fibular fracture	3
Acute tibial fracture	1
Anterior compartment syndrome	7
Anterior tibialis strain	3
Fibular stress fracture	7
Gastroc/ soleus strain	4
Peroneal strain	1
Tibial stress fracture	32
Tibial stress syndrome	24
Tibialis posterior strain	4
Lower leg other	22
Ankle	TOTAL 52
Lateral ankle sprain	44
Medial ankle sprain	2
Ankle other	6
Foot	TOTAL 84
Acute metatarsal fracture	4
Metatarsal stress fracture	17
Metatarsal stress syndrome	2
Neuroma	5
Painful 1 st MTP joint	1
Plantar fasciitis	29
Retrocalcaneal bursitis	1
Sesamoid fracture	2
Sesamoiditis	4
Foot other	19
Other, region unspecified	5
TOTAL	438

Table 8: Summary of prospective injury information collected from the website database.

Injury Category		Incidence of Injury
Back	TOTAL	14
	Back sprain	11
	Disc pathology	1
	Back other	2
Hip/ groin	TOTAL	18
	Gluteal strain/ tendinitis	3
	Greater trochanteritis	1
	Groin strain/ tendinitis	4
	Hip/ groin injury other	6
	Pelvic stress fracture	4
Thigh	TOTAL	45
	Femoral stress fracture	6
	Hamstring strain	24
	Quadriceps strain	5
	Thigh other	10
Knee	TOTAL	56
	IT band friction syndrome	20
	Knee other	7
	Lateral collateral strain	2
	Patellar tendinitis	4
	Patellofemoral pain syndrome	19
	Pes Anserinus tendinitis	4
Lower leg	TOTAL	42
	Achilles tendinitis	7
	Anterior compartment syndrome	4
	Anterior tibialis strain	1
	Fibular stress fracture	1
	Gastroc/ soleus strain	11
	Peroneal strain	1
	Tibial stress fracture	3
	Tibial stress syndrome	6
	Tibialis posterior strain	2
	Lower leg other	6
Ankle	TOTAL	20
	Lateral ankle sprain	12
	Medial ankle sprain	5

Ankle other	3
Foot	TOTAL
Metatarsal stress syndrome	2
Metatarsal stress fracture	1
Painful 1 st MTP joint	2
Plantar fasciitis	8
Retrocalcaneal bursitis	2
Sesamoid fracture	1
Foot other	5
Other, region unspecified	10
TOTAL	226

8) Degrees obtained that are supported by this award

Christine Pollard was funded on this award and will graduate from the University of Massachusetts with a Ph.D. from the Department of Exercise Science in September 2003. Reed Ferber was funded for a two-year Post-doctoral Research Fellowship and graduated from the University of Delaware in July 2003. Kelly Anne McKeown was funded on this award and graduated from the University of Massachusetts with a Masters of Science from the Department of Exercise Science in April of 2002.

9) Employment or research opportunities applied for and/ or received based on experience/ training supported by the grant

Reed Ferber has secured a post-doctoral research fellowship in the Human Performance Laboratory at the University of Calgary, Alberta, Canada. Christine Pollard is currently working as a post-doctoral research fellow at the University of Southern California. Kelly Anne McKeown is currently working as the biomechanist in the Shriners' Hospital Motion Analysis Laboratory in Springfield, MA.

CONCLUSIONS

The overall aim of this research is to gain insight into the etiology of tibial stress fractures using 3-D motion analysis and structural data. Data from 400 subjects will be collected at the University of Delaware and University of Massachusetts (200 at each site) over a 3-year period. 30 of the subjects will have sustained a tibial stress fracture prior to the study and the other 370 will have not. The structural and biomechanical factors leading up to a tibial stress fracture will be assessed. In addition, comparisons will be made of mechanics before and after the stress fracture to determine whether subjects revert back to their pre-injury mechanics.

This Annual Report focused on the third year status of this investigation. Five specific work objectives were outlined and discussed with respect to adherence and methods used to meet all objectives in a timely manner. While there a slight lag in the number of subjects recruited, measures that were taken in 2002 to increase recruitment efforts were successful and continue to be employed. We are confident that by December of 2003, we will be very close to achieving all work objectives.

To date, data on 277 subjects have been collected and analyses performed on retrospective tibial stress fractures, prospective tibial stress fractures and reactions and two subjects who had experienced a tibial stress fracture during the study and returned for reassessment of their running mechanics following recovery and a return to training. In addition, three new conference abstracts were presented on three different common running overuse injuries, highlighting the wide spectrum of injuries that this database is providing valuable information about. Two manuscripts are in preparation, one relating lower extremity mechanics to the incidence of tibial stress fracture and the other is a prospective study of iliotibial band injuries.

Overall, based on these preliminary data, most of the primary hypotheses of the study were supported. These are encouraging results. We are confident that additional data will provide valuable information regarding mechanics and etiology of tibial stress fractures.

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Appendix 1

Abstracts Presented at National and International Conferences.

1) PROSPECTIVE BIOMECHANICAL INVESTIGATION OF ILIOTIBIAL BAND SYNDROME IN COMPETITIVE FEMALE RUNNERS

Presented at the American College of Sports Medicine National Meeting,
San Francisco, CA.

2) REARFOOT MECHANICS IN COMPETITIVE RUNNERS WHO HAD EXPERIENCED PLANTAR FASCIITIS

Presented at the XIXth International Society of Biomechanics Congress, Dunedin, New Zealand.

3) LOWER EXTREMITY MECHANICS IN PATIENTS WITH PATELLOFEMORAL JOINT PAIN: A PROSPECTIVE STUDY

Presented at the American Society of Biomechanics Annual Meeting,
Toledo, OH.

PROSPECTIVE BIOMECHANICAL INVESTIGATION OF ILIOTIBIAL BAND SYNDROME IN COMPETITIVE FEMALE RUNNERS

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Iliotibial band syndrome (ITBS) is one of the most common injuries runners sustain. However, the mechanisms underlying the development of ITBS are not well understood. **PURPOSE:** To prospectively examine differences in running mechanics between runners who sustained ITBS and uninjured controls (CON). **METHODS:** As part of an ongoing investigation, pre-injury biomechanical data were collected for a group of competitive female distance runners ($n=176$). Subjects ran along a 25m runway at a speed of $3.7\pm 0.2\text{m/s}$ and 3D kinetic and kinematic data were recorded for 5 trials. All subjects were asked to report their monthly running mileage and any injuries using a web-based recording system. Six runners who developed ITBS were compared to 6 CON runners who had never experienced any knee or hip related running injuries. Rearfoot eversion (RFEV) and shank (SH) and knee (KN) internal and external rotation (IR:ER) angles and angular velocities were compared using independent t-tests ($P<0.05$). **RESULTS:** No significant differences in monthly running mileage were observed between groups (104.8km vs 124.1km; $P=0.39$). The ITBS group exhibited significantly greater peak RFEV (12.1deg vs 5.6deg; $P=0.02$) and RFEV excursion (14.2deg vs 9.6deg; $P=0.01$) compared to CON. While not significant, the ITBS group also exhibited greater RFEV peak velocity (202.3deg/sec vs 160.0deg/sec; $P=0.13$) compared to CON. The ITBS group demonstrated significantly reduced peak KER (-7.1deg vs -13.0deg; $P=0.02$) and, while not significant, greater peak KNIR (3.7deg vs -3.3deg; $P=0.07$), greater peak SHIR (-11.3deg vs -5.7deg; $P=0.13$), and greater SHIR peak velocity (-160.8 deg/sec vs -121.9 deg/sec; $P=0.10$) compared to CON. **CONCLUSION:** Subjects who experienced ITBS exhibited significantly different gait mechanics than CON. Repetitive exposure to greater RFEV, SHIR, and KNIR may result in excessive torsional forces at the knee necessitating greater passive restraint from the ITB.

Supported by the Department of the Army (DAMD17-00-1-0515)

REARFOOT MECHANICS IN COMPETITIVE RUNNERS WHO HAD EXPERIENCED PLANTAR FASCIITIS

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INTRODUCTION

Plantar fasciitis (PF) is one of the five most common overuse injuries that runners sustain (Mechelen, 1992). It is believed that this injury is a result of repetitive strain to the plantar fascia. Attempts to correlate structural factors to this injury have been unsuccessful (Warren et al, 1984). More recently, Warren et al (1987) reported that runners either currently, or formerly experiencing PF, exhibited greater pronation of the foot while in a loaded stance position than runners with no history of this injury. However the running mechanics associated with PF have received little attention in the literature. Therefore, the purpose of this study was to compare the rearfoot mechanics of runners with a history of PF to a group of uninjured controls. It was hypothesized the PF group would exhibit greater rearfoot motion in terms of eversion at heel strike, peak eversion, eversion excursion and eversion velocity.

METHODS

This is an ongoing study in which, to date, 13 females with a history a PF injury have been compared to 13 females with no history of PF (CON). All subjects were between ages 18-35 and ran between 30-80 miles per week. Subjects ran along a 25m runway at a speed of 3.7 ± 0.2 m/s and 3D kinematic data were recorded for 5 trials. Variables of interest included eversion angle at heel strike (EVatHS), maximum rearfoot eversion angle (MaxEV), eversion excursion (EVEXC), and maximum eversion velocity (EVVEL). Variables were compared using independent t-tests ($P < 0.05$).

RESULTS AND DISCUSSION

Results indicate that the PF group landed in slightly ($P=0.12$) greater eversion at heel strike and exhibited significantly ($P=0.01$) greater maximum rearfoot eversion angle compared to the control group (Table 1; Figure 1). These mechanics could result in placing excessive tension on the plantar fascia. This tension, repeated over many foot contacts likely places a runner at greater risk for PF. The PF group also demonstrated slightly ($P=0.12$) greater EVVEL than the control group. A significant increase in EVVEL would increase the strain rate on the structures resisting foot pronation such as the plantar fascia. Others have also implicated excessive velocity as a contributing cause of running related injuries (Smith et al, 1986). As additional subjects are added to the study, it is possible that this trend towards an increased EVVEL and greater EVatHS will become significant.

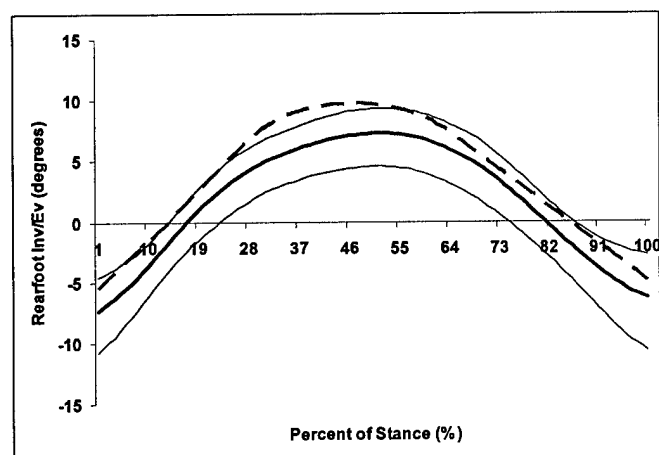


Figure 1: Rearfoot inversion/eversion angular position curves for the stance phase of gait for PF (thick dashed line) and CON groups (solid thick line and thin lines are mean \pm 1SD). Positive values indicate eversion, negative values indicate inversion.

SUMMARY

Subjects who had experienced plantar fasciitis exhibited significantly different rearfoot mechanics than uninjured controls. Exposure to greater rearfoot eversion and eversion velocity may result in excessive linear and torsional forces necessitating greater passive restraint from the plantar fascia. These excessive loads, repeated over many footstrikes could result in producing an inflammatory response in the plantar fascia. However, this study is retrospective in nature and prospective investigations are necessary to further validate these associations.

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ACKNOWLEDGEMENTS

This study has been supported by the Department of the Army (DAMD17-00-1-0515)

Table 1: Mean (SD) of variables of interest for Plantar Fasciitis (PF) and Controls (CON).

Group	EVatHS (degrees)	Max EV (degrees)	EVEXC (degrees)	EVVEL (degrees/sec)
PF	-5.27 (2.53)	9.17 (2.22)	12.43 (2.95)	216.62(65.40)
CON	-6.92 (2.71)	6.30 (2.29)	11.21(2.87)	179.34(52.37)
P-value	0.12	0.01 *	0.30	0.12

Note: * Significantly greater than CON

LOWER EXTREMITY MECHANICS IN PATIENTS WITH PATELLOFEMORAL JOINT PAIN: A PROSPECTIVE STUDY

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INTRODUCTION

The knee is the most common site of injury in runners, with patellofemoral joint pain (PFP) being the most prevalent of knee pathology (Clement et al, 1986). Women have been noted to be twice as likely to experience PFP than their male counterparts. Women have also been consistently noted to have greater Q-angles. A greater Q-angle is thought to increase the lateral component of the quadriceps force vector, thereby increasing the tendency for lateral maltracking. The greater Q-angle noted in women is due to their greater hip width to femoral length ratios (Horton and Hall, 1989). This places the hip in greater adduction than males, putting females at greater risk for knee valgus as well.

These noted structural characteristics are likely to result in gender differences during movement. Ferber et al (2003) reported that females exhibited significantly greater hip adduction and internal rotation as well as greater knee abduction (valgus) during running than males. These differences could lead to abnormal patellofemoral alignment, placing females at greater risk for PFP. For example, increased knee abduction (associated with increased hip adduction) likely increases the functional Q angle and predisposes one to greater risk for patellar malalignment. In addition, femoral adduction is coupled with internal rotation. Excessive femoral internal rotation can also lead to a relative lateral malalignment of the patella. To date there are no studies comparing the 3D hip and knee kinematics

of runners with PFP to that of healthy controls. In addition, while retrospective studies are informative, they do not lend insight into causative mechanisms.

Therefore, the purpose of this study was to compare, prospectively, the 3D kinematics of the hip and knee in female runners who later develop PFP to the mechanics of healthy controls who do not develop this pain. It was hypothesized that runners with PFP would exhibit greater hip adduction and internal rotation, lesser knee internal rotation (due to greater hip internal rotation) and greater knee abduction (valgus) than runners who do not develop PFP.

METHODS

These data are part of an ongoing prospective running injury study of female competitive distance runners. Female runners between the ages of 18 and 45 years and running a minimum of 20 miles per week are included in the study. All subjects undergo an instrumented gait analysis upon entry into the study. Subjects run along a 25 m runway at a speed of 3.65 m/s ($\pm 5\%$). Kinematic data are collected (120 Hz) with a 6-camera Vicon Motion Systems (Oxford, UK) motion analysis system. All kinematic data are filtered at 8 Hz. 3D angles of interest are calculated about a joint coordinate system using MOVE3D (NIH Biomechanics Laboratory, Bethesda, MD). Five trials were averaged for analysis. One-tailed independent t-tests were conducted on the data. Due to the

preliminary nature of the data, an alpha of 0.10 was used for significance.

To date, 9 females have sustained PFP. All injuries were diagnosed by a medical professional. 9 healthy, uninjured females in the same study served as controls (CON). The PFP females were 33.4 yrs old (sd 8.2) and ran an average of 27 mpw. The CON were 29.9 yrs (sd 11.3) and ran 29 mpw.

RESULTS and DISCUSSION

Table 1 presents the comparison between the PFP and CON for the variables of interest. It is interesting to note that while excessive rearfoot eversion is thought to be associated with PFP, the values were identical between groups.

Table 1. Variables of interest (sd) for PFP and CON

(values in deg)	PFP	CON	p
Pk Eversion	8.7 (3.2)	8.7 (3.2)	0.50
Kn Add.	4.4 (3.2)	5.3 (3.3)	0.28
Kn IR	2.5 (5.7)	2.4 (6.9)	0.47
Hip Add	9.4 (5.4)	6.7 (2.9)	0.10*
Hip ER	5.1 (9.3)	10.2 (4.9)	0.08*
Q-Angle	16.1 (4.0)	13.0 (3.1)	0.05*

Peak knee adduction was not significantly different between groups. However, greater knee adduction excursion can be seen in Figure 1. The same is true for knee internal rotation excursion. When moving up to the hip, peak adduction was greater, as expected in the PFP subjects. In addition, the hip was in greater internal rotation at footstrike, and remained in greater internal rotation throughout stance (Figure 2).

Another interesting finding was the significantly greater Q angle noted in the PFP subjects. This structural difference coupled with the subtle kinematic differences could significantly alter the distribution of loading across the patellofemoral joint.

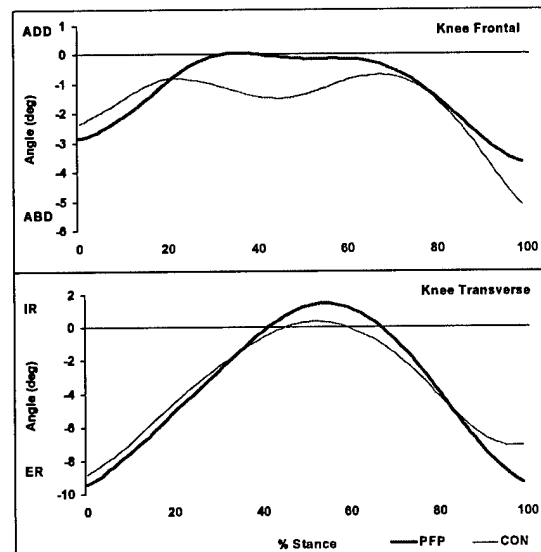


Figure 1. Knee Frontal and Transverse Motions (PFP vs CON)

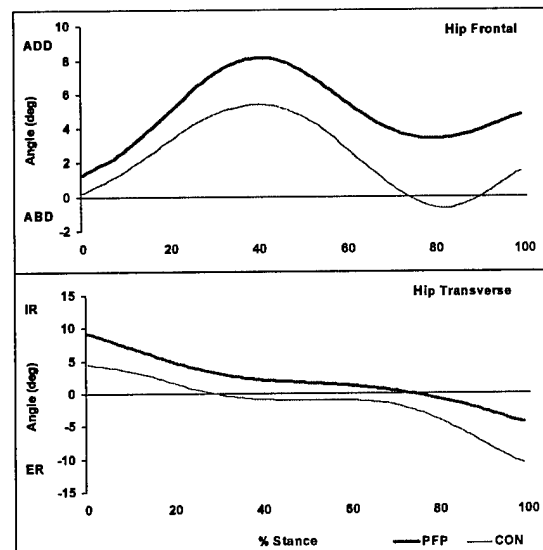


Figure 2. Hip Frontal and Transverse Motions (PFP vs CON)

SUMMARY

It is clearly difficult to infer patellofemoral kinematics and associated loading patterns from tibiofemoral kinematics. However, these preliminary data suggest there are some differences, noted prospectively, in the hip and knee mechanics of runners who develop PFP compared to those who do not. Additional differences may become evident as subjects are added to the study.

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Appendix 2

Advertisement Flyer

A black and white line drawing of a female athlete in a running pose. She is wearing a tank top, shorts, and running shoes, with her hair tied back.

A black and white line drawing of a female athlete in motion, running towards the right. She is wearing a tank top, shorts, and athletic shoes. Her hair is tied back, and she has a determined expression. The drawing is simple, using bold lines to define her form and movement.

- ### **Inclusion Criteria:**

- Please contact Clare Milner at 302-831-4646 or milner@udel.edu**

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Appendix 3

Curriculum Vitae for Irene S. McClay

Irene S. Davis
Curriculum Vitae

PII Redacted

EDUCATION

PhD	1990	Pennsylvania State University	Biomechanics
MEd	1984	University of Virginia	Biomechanics
BS	1978	University of Florida	Physical Therapy
BS	1977	University of Mass.	Exercise Science

EMPLOYMENT

Director of Research, Joyner Sportsmedicine Institute, (6/97 - present)

Development of research within the Joyner Sportsmedicine Institute aimed at advancing the science of sportsmedicine and improving prevention, diagnosis and treatment of sports-related injuries.

Associate Professor, Program in Physical Therapy, University of Delaware. (5/97 - present)

Assistant Professor, Program in Physical Therapy, University of Delaware. (9/89 - 5/97)

Instruction of graduate students in physical therapy. Research in clinical biomechanics with specific interest in lower extremity mechanics and injury. Director, Running Injury Clinic.

Research Assistant, Pennsylvania State University, Center for Locomotion Studies. (8/85 - 6/89)

Responsible for the development and coordination of the Running Injury Clinic and Orthopedic Clinic. Research activities in locomotor biomechanics. Consultant to the Distance Runner's Camp at US Olympic Training Center.

Research and Teaching Assistant, University of Virginia, Rehabilitation Engineering Center. (8/82-8/85)

Research activities in wheelchair ergonomics. Instructor of graduate courses in biomechanics and human dissection. Co-coordinator of the Arts and Science of Sports Medicine Conference held annually at the University of Virginia (6/84, 6/85)

Physical Therapist, Blue Ridge Rehabilitation Associates, Charlottesville, VA (1/83 - 7/85)
Part time home health and private practice physical therapy.

Physical Therapist, Woodrow Wilson Rehabilitation Center, Fishersville, VA (2/79 - 6/82)
Patient treatment, supervision of physical therapy students, inservice training and
Coordinator of the Amputee Clinic. Instructor in continuing education course in
Management of the Spinal Cord Injured Patient.

GRANTS

Gender Bias and ACL Injuries: Risk Factors and Interventions (in review). R01 submitted to the National Institutes of Health for **\$1.70 million** for 5 years.

Gait Retraining in Runners (in review). R03 submitted to the National Institutes of Health (NIAMS) for **\$150,000** for 2 yrs.

The Effect of Wedged Foot Orthoses on Lower Extremity Mechanics and Function in Patients with Knee Osteoarthritis. National Institutes of Health (COBRE Grant) **\$932,815** for 5 years beginning 02/2002.

A Comparison of Custom and Semicustom Foot Orthotic Devices on Lower Extremity Mechanics and Comfort. The Pauline Marshall Research and Education Foundation, **\$15,000** for one year grant period beginning 9/2001 .

Biomechanical Factors Associated with the Etiology of Stress Fractures in Runners. The Department of the Army. **\$1.05 million** for 5 yr grant period beginning 9/2000.

2 Doctoral Scholarship. **\$20,000**. Joyner Sportsmedicine Institute, 1998, 1999, 2000, 2001; **\$36,000** for 2002. 2003

Undergraduate Summer Scholarship. **\$4,000**. Joyner Sportsmedicine Institute, 1997 and 1998, 1999, 2000, 2001

A Comparison of Four Methods to Obtain a Negative Impression of the Foot, **\$3,250**, Foot Management, Inc, 1998-1999

The Effect of Different Orthotic Devices on Lower Extremity Mechanics of Rearfoot and Forefoot Strikers, **\$3,500**. Foot Management, Inc, 1999-2000.

The Effect of the Protonics System on Patellar Alignment and Gait in Patients with Patellofemoral Joint Pain. **\$18,000**. Funded by Inverse Technology, 1998-1999

Clinical Efficacy of the Protonics System in Patients with Patellofemoral Joint Pain. **\$3,000**. Funded by Inverse Technology, 1998-1999

A Comparison of Strengthening vs. Orthotics on Pronation and Pronation Velocity. Funded by the Physical Therapy Foundation **\$60,000**, 1993-1995

Lower Extremity Mechanics and Injury. Funded by the Whitaker Foundation **\$180,000**, 1993-1996.

- The Relationship between Subtalar Joint Axis Orientation, Joint Motion and Injuries in Runners. Funded by the Biomedical Research Support Grant. \$2550, 1992
- The Relationship between Subtalar Joint and Knee Joint Motion in Runners. Funded by the University of Delaware Research Foundation. \$16,000, 1990.
- A Comparison of Patellofemoral 3-D Kinematics in Runners with and without Patellofemoral Pain. Doctoral Dissertation. Foundation for Physical Therapy. \$8500, 1988.

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McClay, IS & Manal, KT Lower Extremity Kinetic Comparisons between Forefoot and Rearfoot Strikers. Presented at the American Society of Biomechanics Meeting, Stanford, CA 8/95

McClay, IS & Manal, KT Coupling Parameters in Runners who Pronate and Normals. Presented at the American Society of Biomechanics Meeting, Columbus, Ohio, 11/94.

McClay, IS & Manal, KT (1995). A Comparison of Two- and Three-dimensional Lower Extremity Kinematics during Running between Pronators and Normals. (Presented at the American Society of Biomechanics Meeting, Columbus, Ohio, 11/94.

McClay, IS, Cavanagh, PR, Sommer, HJ, & Kalenak, A: "Three-Dimensional Kinematics of the Patellofemoral Joint during Running". Proceedings of the American Society of Biomechanics Meeting, 10/91, Tempe, AZ.

McClay, IS, Cavanagh, PR, Sommer, HJ, & Kalenak, A: "The Effect of Orthotic Treatment on Tibiofemoral and Patellofemoral Joint Kinematics". *Physical Therapy*, 71(6):S46-7, 1991.

McClay, IS, Cavanagh, PR, Sommer, HJ, Woltring, HJ, & Kalenak, A: "Three-Dimensional Angular Kinematics of the Tibiofemoral Joint During Running". Proceedings of the International Symposium on 3-D Analysis of Human Movement, Montreal, 7/91.

Cavanagh, PR, Robinson, JR & McClay, IS: "Biomechanical Perspective of Stress Fractures in Professional Basketball Players". *Med Sci Sport and Exercise* 22:(2) S104, April, 1990.

Woltring, HJ, McClay, IS, & Cavanagh, PR: "3-D Photogrammetric Camera Calibration without a Calibration Object." Abstract published in the Proceedings of the International Society of Biomechanics Meeting, Los Angeles, CA, 6/89.

McClay, IS, Cavanagh, PR, & Kalenak, A: "Biomechanical Evaluation of the Injured Runner" Abstract published in the Proceedings of the East Coast Gait Conference, November, 1987.

Brubaker, CE, McClay, IS, & McLaurin, CA: "Effect of Seat Position of Propulsion Efficiency." Proceedings of the 2nd International Conference on Rehabilitation Engineering, 1984, pp. 134-138.

Brubaker, CE, McClay, IS, & McLaurin, CA: "The Effect of Mechanical Advantage on Lever Propulsion Efficiency". Proceedings of the 6th Annual Conference on Rehabilitation Technology, 1983, pp. 122-124.

SELECTED INVITED PRESENTATIONS

"Biomechanical Considerations for Various Types of Foot Orthoses" Presented in the minisymposium titled "Clinical and Biomechanical Efficacy of Foot Orthoses" at the American College of Sports Medicine Mtg in San Francisco, CA, May, 2003.

"Influence of Foot and Ankle Mechanics of Patellofemoral Joint Dysfunction: A Ground Up Biomechanical Perspective. Presented in the minisymposium titled "The Influence of

Lower Quarter Mechanics on Patellofemoral Joint Dysfunction" at the American College of Sports Medicine Mtg in San Francisco, CA, May, 2003.

"Case Studies in the Injured Runner" Presented at the Medical Aspects of Sports Medicine Mtg, University of Delaware, March, 2003.

"Evidence for the Effect of Foot Orthoses on Lower Extremity Mechanics" Presented at Temple University College of Podiatric Medicine. February, 2003

"The Relationship between Structure and Function in the Foot and Ankle". Presented at the Foot Management Inc. Mtg, Ocean City, MD, October 2002

"Normal and Abnormal Gait" Presented at the Foot Management Inc. Mtg, Ocean City, MD, October 2002

"The Effect of the Inverted Orthotic on Lower Extremity Mechanics in Patients with Patellofemoral Joint Pain. Presented at the Prescription Foot Orthotic Laboratory of America (PFOLA) Mtg, Montreal, Canada, October 2002.

"Structural Deformities of the Foot: Assessment and Clinical Implications" Presented at the National Athletic Trainers Association Mtg, Dallas, TX, June, 2002

"Running Mechanics and Injury" Presented at the National Athletic Trainers Association Mtg, Dallas, TX, June, 2002

"The Role of Core Instability in Lower Extremity Injuries" Symposium: ACL Injuries and the Gender Bias. Presented at the American College of Sports Medicine Mtg in St. Louis, May, 2002.

"Biomechanical Case Studies in Running Injuries" Symposium: Evidence for injury mechanisms in runners. Presented at the American College of Sports Medicine Mtg in St. Louis, May, 2002.

"The Application of Biomechanics to Sports Medicine: Focus on Running Injuries" Keynote presentation at the Midwest Student Biomechanics Symposium, Normal, IL, March, 2002.

"Core Instability and Lower Extremity Mechanics: Implications for Injury." Presented at the Combined Sections Meeting of the APTA, Boston, MA, February, 2002.

"An Update on the Mechanics behind the Success of Orthotic Intervention" Presented at Temple University School of Podiatric Medicine evening seminar series, Philadelphia, PA, February 2002.

"The Effect of the Inverted Orthotic on Lower Extremity Mechanics: An Update" Presented at the Prescription Foot Orthotic Laboratory Association Annual Meeting, Miami, FL, November, 2001

- "How Do Foot Orthotic Devices Influence Lower Extremity Mechanics: Evidence from the Literature. Presented at the Prescription Foot Orthotic Laboratory Association Annual Meeting, Miami, FL, November, 2001
- "Selected Case Studies in Running Injuries" Presented at the Combined Sections Meeting of the APTA, San Antonio, TX, Feb, 2001.
- "Developing Standards in Epidemiological Research" Presented at the National ACSM Mtg in Indianapolis, June, 2000
- "Lower Extremity Mechanics and Injury Patterns in High and Low Arch Runners". Keynote Presented at the Foot and Ankle Research Retreat, Annapolis, MD, May, 2000
- "Effect of the Inverted Orthotic on Rearfoot and Knee Mechanics" Presented at the 4th Annual John Weed Seminar, Palm Springs, CA, March, 2000 and the PFOLA meeting in Vancouver, BC, November 2000
- "Influence of foot, knee and hip coupling on patellofemoral mechanics" Symposium at the Combined Sections Meeting of the APTA, New Orleans, LA, February, 2000 and at the National ACSM Mtg in Indianapolis, June, 2000, and the Arts and Science of Sports Medicine, Charlottesville, VA, June, 2000.
- "Visual Gait Analysis in Runners" Presented at the Arts and Science of Sports Medicine, Charlottesville, VA, June, 2000.
- "Injury Mechanisms in Runners" Keynote speaker at the Fifth IOC Congress on Sport Sciences, Sydney, Australia, November, 1999
- "Clinical Gait Analysis" Keynote speaker at the Fifth IOC Congress on Sport Sciences, Sydney, Australia, November, 1999.
- "Risk Factors in Anterior Cruciate Ligament Injuries" Clinical Colloquium presented at the National ACSM Mtg, in Seattle, WA, 6/99
- "Problem Solving the Injured Runner" Clinical Colloquium presented at the National ACSM Mtg, in Seattle, WA, 6/99
- "Coupling between the Foot and the Knee in Runners" Presented at Joyner Sportsmedicine Institute National Conference, Hilton Head, SC, 10/99
- "Biomechanics of the Knee" Presented at Joyner Sportsmedicine Institute National Conference, Hilton Head, SC, 10/99
- "Physical Therapist to Marathoner - A Classical Tale of Overuse." Presented at the Case Conference Seminar at the Annual Conference of the American Physical Therapy Association, Minneapolis, MN, 6/98.
- Eugene Michels Research Forum - "Instrumented versus Visual Gait Analysis in Clinical Assessments" Presented at the Combined Sections Meeting in Dallas, TX, 2/97.

- "Biomechanical Differences between Forefoot and Rearfoot Strikers" presented at the Joyner Sportsmedicine Institute 1996 National Conference, Hilton Head, SC, 11/96.
- "Plantar Fasciitis: A Case Study" Presented at the Case Conference Seminar at the Annual Conference of the American Physical Therapy Association, Minneapolis, MN, 6/96.
- "The Use of Motion Analysis in Physical Therapy". University of PA, Philadelphia, 10/95.
- "The Patellofemoral Joint - Implications of the study of three-dimensional kinematics". Grand Rounds, Dept. of Orthopedic Surgery, Hershey Medical Center, 1/95.
- "What is Clinical Research". Keynote Address at Research Symposium, Shenandoah University, 4/94.
- "Research in Foot and Ankle Biomechanics". Presented at the Combined Sections Meeting of the American Physical Therapy Association, New Orleans, LA, 2/94
- "Biomechanical Assessment of Gait" Presented at the Arts and Science of Sports Medicine Conference, Charlottesville, Va., 6/93
- "Closed Kinetic Chain Activities for the Foot and Ankle" Presented at the Foot and Ankle Seminar for HealthSouth in Orlando, FL, 2/93, Phoenix, AZ, 3/93, St. Louis, MO, 4/93 and for Foot Mgt, Inc in Ocean City, MD in 10/94 and 4/96.
- "Normal Structure and Gait". Presented at the Arts and Science of Sports Medicine Conference, Charlottesville, Va., 6/92, and at the Symposium on the Biomechanics of the Lower Extremity, NATA, Denver, CO, 2/92.
- "Abnormal Structure and Gait". Presented at the Arts and Science of Sports Medicine Conference, Charlottesville, Va., 6/92, and at the Symposium on the Biomechanics of the Lower Extremity, NATA, Denver, CO, 2/92 and for Foot Mgt, Inc in Ocean City, MD in 10/94 and 4/96.
- "The Biomechanical Evaluation of the Injured Runner". Presented at the Medical Symposium of the Penn Relays, 4/92, The Arts and Science of Sports Medicine Conference, Charlottesville, Va., 6/88 and the East Coast Gait Conference, Bethesda, Md, 11/87
- "Biomechanics of the Foot and Ankle". Presented at the Arts and Science of Sports Medicine Conference, Charlottesville, Va., 6/91.
- "Relationship between Mechanics and Running Injuries". Presented at the Arts and Science of Sports Medicine Conference, Charlottesville, Va., 6/91.
- "Anatomy and Biomechanics of the Patellofemoral Joint". Presented at the Sports Physical Therapy Meeting, Orlando, Fla. 12/90.
- "Relationship between Structure and Function in Patellofemoral Disorders". Presented at the Sports Physical Therapy Meeting, Orlando, Fla. 12/90.

"Normal and Abnormal Running Mechanics". Presented at the Arts and Science of Sports Medicine Conference, Charlottesville, Va. 6/90.

"Biomechanical Perspective of Stress Fractures in Professional Basketball Players". Presented at the Annual Meeting of the NBA Physicians, West Palm Beach, FL, 11/88.

"The Biomechanics of Patellofemoral Disorders". Presented at the Arts and Science of Sports Medicine Conference, Charlottesville, Va., 6/88.

"Biomechanical Profile of Elite Woman Distance Runners". Presented at the Dogwood Festival Pre-race Conference, Atlanta, GA, 7/88.

HONORS

Fellow, American College of Sports Medicine	2001
Summa Cum Laude Graduate, The Penn State University	1990
Physical Therapy Foundation Scholar	1988
Recipient of Zipser Scholarship, The Penn State University	1988
Outstanding Masters Student Award, University of Virginia	1984
Nominee for Mary McMillan Scholarship Award, APTA	1978
Magna Cum Laude Graduate, University of Florida	1978
Magna Cum Laude Graduate, University of Massachusetts	1977

PROFESSIONAL ACTIVITIES

Societies	American Society of Biomechanics
	Organizing Committee, Annual ASB Mtg, Chicago, IL, July 2000
	Membership Committee (1997-2001)
	Scientific Committee for the Third International Symposium on 3-D Analysis of Human Movement, Stockholm, Sweden, 1994
	American College of Sports Medicine, Fellow
	American Physical Therapy Association (APTA)
	Orthopedic and Research Sections Member
	Chairperson of Research Committee of the Foot and Ankle Special Interest Group (1997-present)
Advisory	International Society of Biomechanics
	Invited Participant to the "Working Conference on Gait Analysis in Rehabilitation Medicine" National Institutes for Health, September, 1996
	Doctoral Research Advisory Committee, American Physical Therapy Association (1995-1997)
	Medical Consultant for Runners World (1995-present)
Ed. Board	Clinical Biomechanics (1999-present)
	Journal of Orthopedic and Sports Physical Therapy (1996-1997)
	Journal of Applied Biomechanics (1997-1999)

Reviewer Journal of Biomechanics
Medicine and Science in Sports and Exercise
Foot and Ankle, International
Journal of the American Podiatric Medical Association
Journal of Applied Biomechanics

Other **Organizing Chair for Research Retreat - Measurement of Foot Motion: Forward
and Inverse Dynamic Models, University of Southern California, Los
Angeles, CA, April, 2004**

Organizing Chair for Research Retreat - ACL Injuries: The Gender Bias. Lexington, KY,
April 2001, 2003

Organizing Chair for Research Retreat - Static and Dynamic Classification of the Foot.
Annapolis, MD, May, 2000.

Licensure Licensed Physical Therapist, State of Delaware

Appendix 4

Curriculum Vitae for Joseph Hamill

CURRICULUM VITAE

Joseph Hamill

Professor and Chair
Department of Exercise Science
Director, Biomechanics Laboratory
University of Massachusetts Amherst
and
Professor
Neuroscience and Behavior Program
University of Massachusetts Amherst

BUSINESS ADDRESS:

Biomechanics Laboratory
Department of Exercise Science
University of Massachusetts
Amherst, MA 01003
(413) 545-2245
(413) 545-2906 Fax
jhamill@excsci.umass.edu

PII Redacted

EDUCATION

1967	Teaching Certificate	Lakeshore Teacher's College, Toronto, Canada
1972	B.A.	York University, Toronto, Canada
1977	B.S. (magna cum laude)	Concordia University, Montreal, Canada
1978	M.S.	University of Oregon, Eugene, Oregon
1981	Ph.D.	University of Oregon, Eugene, Oregon

Undergraduate Areas of Study: Political Science
General Science

Graduate Area of Study: Biomechanics

RESEARCH INTERESTS

Mechanics of lower extremity function
Mechanical Analysis of normal and pathological gait.
Modeling the lower extremity in gait.
Optimality criteria in human locomotion
Dynamical Systems

EMPLOYMENT EXPERIENCE

1981-1982	Post-doctoral Fellow Biomechanics Laboratory, University of Oregon
1982-1985	Assistant Professor (Biomechanics) Department of Physical Education, Southern Illinois University
1985-1986	Assistant Professor (Biomechanics) and Graduate Program Director Department of Physical Education, Southern Illinois University
1986-1988	Assistant Professor (Biomechanics) Department of Exercise Science, University of Massachusetts
1989-1995	Associate Professor (Biomechanics) and Graduate Program Director Department of Exercise Science, University of Massachusetts
1990-1995	Adjunct Professor Department of Medicine, University of Massachusetts Medical Center
1995-1996	Associate Professor (Biomechanics) and Department Chair Department of Exercise Science, University of Massachusetts
1996-	Professor (Biomechanics) and Department Chair Department of Exercise Science, University of Massachusetts

RESPONSIBILITIES OF PRESENT POSITION

Department Chair
Director of the Biomechanics Laboratory
Teach graduate and undergraduate courses in Biomechanics
Advise undergraduate and graduate students
Chair graduate theses and dissertations in the Department
Conduct research in the area of Biomechanics
Secure external funding for the Biomechanics Laboratory

TEACHING RESPONSIBILITIES

At Southern Illinois University

Undergraduate

P.E. 302

P.E. 370

Kinesiology for Physical Therapy

Tests and Measurements

Graduate

P.E. 511

P.E. 512

P.E. 505A

P.E. 505B

P.E. 505C

P.E. 561

Mechanical Analysis

Biomechanics of Sport

Biomechanics Instrumentation

Computer Applications

Biomechanics of the Musculo-skeletal System

Doctoral Seminar

At University of Massachusetts

Undergraduate

Ex Sc 300

Ex Sc 305

Ex Sc 304

Ex Sc 311

Ex Sc 474

Writing Seminar for Exercise Science

Kinesiology

Human Anatomy

Anatomy of Human Motion

Measurement and Evaluation Theory

Graduate

Ex Sc 531

Ex Sc 611

Ex Sc 732

Ex Sc 892

Ex Sc 895

Mechanical Analysis of Human Motion

Introduction to Research

Advanced Biomechanics

Doctoral Seminar

Clinical Biomechanics Seminar

UNIVERSITY SERVICE

Department Committees

Master's Thesis Review Committee, 1982-1983

Comprehensive Examination Review Committee, 1983-1984

Chair, Graduate Faculty, 1982-1986

Chair, Search Committee for Department Chairperson, 1986

Graduate Committee, 1986-

Telecommunications Committee, 1988-1990

Chair, Department Personnel Committee, 1994-1995

Chair, Motor Control Search Committee, 1994-1995

College Committees

College Computer Advisory Committee, 1982-1986

School Personnel Committee, 1994-1995

School Executive Committee, 1995-

Member, School Development Officer Search Committee, 1997.
University Committees
Graduate Council, 1991
Recruitment and Retention Committee, 1991-92
Research Council, 1992-1995
Life Sciences Institute Advisory Council, 2003-

PROFESSIONAL ORGANIZATIONS

American Alliance for Health, Physical Education, Recreation and Dance
Biomechanics Academy of the Research Consortium
International Society of Biomechanics
Canadian Society of Biomechanics
American Society of Biomechanics
American College of Sports Medicine
New England College of Sports Medicine
International Society of Biomechanics in Sport
ASTM

RESEARCH AFFILIATIONS

Scientific Advisory Board, Rockport Walking Institute, 1986-1992.
Scientific Advisory Board, LifeFitness, Inc., 1993-
Scientific Advisory Board, USA Field Hockey, 1995-1998
USA Volleyball Sports Medicine and Performance Commission's Resource Advisory Committee, 1996-1999

ACADEMIC HONORS

Fellow, Research Consortium of the AAHPERD, 1984
Fellow, American College of Sports Medicine, 1986
Fellow, American Academy of Kinesiology and Physical Education, 1997

OFFICES IN PROFESSIONAL ORGANIZATIONS

1. Chair-elect, Kinesiology Academy, 1990-91.
2. Board Member, International Society of Biomechanics in Sports, 1992-94.
3. Chair, Biomechanics Interest Group of the American College of Sports Medicine, 1996-97.
4. Member-at-large, Executive Committee of the New England Chapter of the American College of Sports Medicine, 1995-1997.

5. Board Member, International Society of Biomechanics Technical Group on Footwear, 1998-2000.
6. Member, Credentials Committee, American College of Sports Medicine, 2000-2003.
7. Member-at-Large, Executive Board of Canadian Society of Biomechanics, 2000-
8. Member, Executive Board of the International Society of Biomechanics, 2003-

PROFESSIONAL SERVICE

Review Committees For Professional Meetings

1. Abstract Review Committee, American College of Sports Medicine Annual Meeting, 1989.
2. Abstract Review Committee, American College of Sports Medicine Annual Meeting, 1990.
3. Program Committee, combined meeting of the 9th International Symposium on Biomechanics in Sports and the Kinesiology Academy, June 29 - July 7, 1991.
4. Abstract Review Committee, American College of Sports Medicine Annual Meeting, 1991.
5. Review Panel Chair for Research Consortium, AAHPERD Convention, 1991-92.
6. Abstract Review Committee, American College of Sports Medicine Annual Meeting, 1992.
7. Review Panel Chair for Research Consortium, AAHPERD Convention, 1992-93.
8. Abstract Review Committee, American College of Sports Medicine Annual Meeting, 1993.
9. Abstract Review Committee, American College of Sports Medicine Annual Meeting, 1994.
10. Scientific Committee, International Society of Biomechanics in Sports Annual Meeting, Budapest, Hungary, June 1-6, 1994.
11. Abstract Review Committee, American College of Sports Medicine Annual Meeting, 1995.
12. Member, Scientific Review Committee, International Society of Biomechanics in Sports Annual Meeting, Madiera, Portugal, 1995-96.
13. Program Committee, New England American College of Sports Medicine Annual Meeting, Providence, RI, 1999.
14. Program Committee, New England American College of Sports Medicine Annual Meeting, Providence, RI, 2000.
15. Abstract Reviewer, XVIIIth Congress of the International Society of Biomechanics, ETH Zurich, Switzerland, July, 2001.
16. Abstract Reviewer, Vth Symposium of the Footwear Working Group Symposium of the International Society of Biomechanics, July, 2001.
17. Member, Research Consortium Research Writing Award Committee, 2001.
18. Member, Holyoke Community College Department of Health and Fitness Advisory Board, 2001-
19. Member, Scientific Review Committee, International Society of Biomechanics in Sports Annual Meeting, Caceres, Spain, 2002.
20. Member, Scientific Review Committee, International Society of Biomechanics in Sports Annual Meeting, Beijing, China, 2003.

External Reviewer for Theses and Dissertations

1. External Dissertation Reviewer, McMaster University, Hamilton, Ontario, Canada, June, 1995.
2. External Thesis Reviewer, Lakehead University, Thunder Bay, Ontario, Canada, June, 1995.

3. External Dissertation Reviewer, University of Guelph, Guelph, Ontario, Canada, January, 1997.
4. External Dissertation Reviewer, University of Connecticut, Storrs, Connecticut, December, 1998.
5. External Dissertation Reviewer, University of Delaware, Newark, Delaware, March, 2000.
6. External Thesis Reviewer, University of Delaware, Newark, Delaware, November, 2000.
7. External Dissertation Reviewer, University of Calgary, Calgary, Alberta, Canada, November, 2002.

External Grant Reviewer

1. External Reviewer for internal grants at University of Texas at Tyler, 1991.
2. Grant Reviewer, Natural Sciences and Engineering Council of Canada, 1993.
3. External Grant Reviewer, University Grants Committee, Hong Kong, February, 1998.
4. External Grant Reviewer, Natural Sciences and Engineering Council of Canada, May, 2000.
5. External Grant Reviewer, Canadian Institutes of Health Research, April, 2003.

Committee Member

1. Biomechanics Model Research Laboratory, Olympic Scientific Congress, University of Oregon, July, 1984.
2. Completed Research in Health, Physical Education, Recreation and Dance, 1986.
3. Research Consortium Program Review Committee, AAHPERD Annual Convention, April, 1987.
4. Kinesiology Academy, Nominating Board for Officers, 1987.
5. Completed Research in Health, Physical Education, Recreation and Dance, 1988.
6. Nominating Committee for Kinesiology Academy Chair, 1991.
7. Delegate to American Alliance Assembly, January 1, 1991 to December 31, 1991.
8. ASTM Committee F-8 on Sports Equipment and Facilities, June, 1992.
9. Conference Chair, International Society of Biomechanics in Sport Annual Meeting, University of Massachusetts Amherst, June 23-26, 1993.
10. Doctoral Program Evaluation Committee, American Academy of Kinesiology and Physical Education, 1997.
11. Program Review Committee for Biomechanics, Michigan State University, East Lansing, MI, January, 2000.
12. Continuing Committee for Doctoral Program Review, American Academy of Kinesiology and Physical Education, 2001-2002
13. Member, Research Consortium Research Writing Award Committee, 2001.
14. Member, AAHPERD Grant Proposal Committee, 2001.
15. Member, Holyoke Community College Department of Health and Fitness Advisory Board, 2001-

EDITORIAL BOARD OF PROFESSIONAL JOURNALS

Member, Editorial Review Board, *Pediatric Exercise Science*, 1988-

Member, Editorial Review Board, *Medicine, Exercise, Nutrition, and Health*, 1991-1995
 Guest Editor, Special Issue of *Pediatric Exercise Science*, The Physically Challenged Child, May, 1992.
 Section Editor, Biomechanics, *Research Quarterly for Exercise and Sport*, 1993-96
 Member, Editorial Review Board, *Journal of Applied Biomechanics*, 1996-1999
 Member, Editorial Board, *Research Quarterly for Exercise and Sport*, 1998-1999
 Associate Editor, *Medicine and Science in Sports and Exercise*, 2000-2002
 Member, Editorial Review Board, *Sports Biomechanics*, 2000-
 Member, Editorial Review Board, *Journal of Sports Sciences*, 2001-

AD HOC REVIEWER FOR PROFESSIONAL JOURNALS

Reviewer, *Medicine and Science in Sports and Exercise*, 1985-
 Reviewer, *International Journal of Sports Biomechanics*, 1986-
 Reviewer, *Research Quarterly for Exercise and Sport*, 1989-
 Reviewer, *Sports Medicine*, 1991-
 Reviewer, *Journal of Gerontology*, 1991-
 Reviewer, *Journal of Orthopedic and Sports Physical Therapy*, 1991-
 Reviewer, *Journal of Applied Biomechanics*, 1993-
 Reviewer, *Journal of Applied Physiology*, 1993-
 Reviewer, *Journal of Biomechanics*, 1993-
 Reviewer, *Clinical Journal of Sports Medicine*, 1996-
 Reviewer, *British Journal of Sports Medicine*, 1996-
 Reviewer, *Clinical Biomechanics*, 1999-
 Reviewer, *Exercise and Sports Science Review*, 2000-
 Reviewer, *European Journal of Applied Physiology*, 2000-
 Reviewer, *Journal of Rehabilitation Research and Development*, 2002-

PUBLICATIONS

Osternig, L. R., Sawhill, J. A., Bates, B. T., **Hamill, J.** A method for rapid collection and processing of isokinetic data. *Research Quarterly for Exercise and Sport* 53(3):252-257, 1982.

Knutzen, K. M., Bates, B. T., **Hamill, J.** Electrogoniometry of post surgical knee bracing in running. *American Journal of Physical Medicine* 62(4):172-181, 1983.

Osternig, L. R., **Hamill, J.**, Sawhill, J. A., Bates, B. T. Influence of torque and joint speed on power production. *American Journal of Physical Medicine* 62(4): 163-171, 1983.

Hamill, J., Bates, B. T., Sawhill, J. A., Knutzen, K. M. Variations in ground reaction force parameters at different running speeds. *Human Movement Sciences* 2:47-56, 1983.

Hamill, J., Bates, B. T., Knutzen, K. M. Ground reaction force symmetry during walking and running. *Research Quarterly for Exercise and Sport* 55(3):289-293, 1984.

Knutzen, K. M., Bates, B. T., **Hamill, J.** Knee brace influences on the tibial rotation and torque patterns of the surgical limb. *Journal of Orthopaedic and Sports Physical Therapy* 6(2):116-122, 1984.

Osternig, L. R., **Hamill, J.**, Corcos, D. M., Lander, J. E. Electromyographic patterns accompanying isokinetic exercise under varying speed and sequencing conditions. *American Journal of Physical Medicine* 63(6):289-297, 1984.

Knutzen, K. M., **Hamill, J.**, Bates, B. T. Ambulatory characteristics of the visually disabled. *Human Movement Sciences* 4:55-66, 1985.

Lander, J. E., Bates, B. T., Sawhill, J. A., **Hamill, J.** A comparison between free-weight and isokinetic bench pressing. *Medicine and Science in Sports and Exercise* 17(3): 344-353, 1985.

Smith, P. K., **Hamill, J.** The effect of punching glove type and skill level on momentum transfer. *Human Movement Studies* 12(3):153-161, 1986.

Hamill, J., Knutzen, K. M., Bates, B. T., Kirkpatrick, G. M. Evaluation of two ankle appliances using ground reaction force data. *Journal of Orthopaedic and Sports Physical Therapy* 7(5):244-249, 1986.

Osternig, L. R., **Hamill, J.**, Lander, J. E., Robertson, R. Coactivation of sprinter and distance runner agonist/antagonist muscles in isokinetic exercise. *Medicine and Science in Sports and Exercise* 18(4):431-435, 1986.

Hamill, J., Ricard, M. D., Golden, D. M. Angular momentum in multiple rotation non-twisting platform dives. *International Journal of Sport Biomechanics* 2(2): 78-87, 1986.

Knutzen, K. M., Bates, B. T., Schot, P., **Hamill, J.** Knee brace evaluation. *Medicine and Science in Sports and Exercise* 19(3):303-309, 1987.

Hamill, J., Murphy, M. V., Sussman, D. H. The effects of track turns on lower extremity function. *International Journal of Sport Biomechanics* 3(3):276-286, 1987.

Hamill, J., Morin, G., Clarkson, P. M., Andres, R. O. Exercise moderation of foot function during walking with a re-usable semirigid ankle orthosis. *Clinical Biomechanics* 3(3):153-158, 1988.

Hamill, J., Bates, B. T. A kinetic evaluation of the effects of in vivo loading on running shoes. *Journal of Orthopaedic and Sports Physical Therapy* 10(2):47-53, 1988.

Hamill, J., Freedson, P. S., Boda, W., Reichsman, F. Effects of shoe type and cardiorespiratory responses and rearfoot motion during treadmill running. *Medicine and Science in Sports and Exercise* 20(5):515-521, 1988.

Greer, N. L., **Hamill, J.**, Campbell, K. R. Ground reaction forces in children's gait. *Pediatric Exercise Science* 1(1):45-53, 1989.

Hamill, J., Knutzen, K. M., Bates, B. T., Kirkpatrick, G. M. Relationship of static and dynamic measures of the lower extremity. *Clinical Biomechanics* 4(4):217-225, 1989.

Greer, N. L., **Hamill, J.**, Campbell, K. R. Dynamics of children's gait. *Human Movement Sciences* 8:465-480, 1989.

Brown, D. B., Knowlton, R. G., **Hamill, J.**, Schneider, T. L., Hetzler, R. K. Physiological and biomechanical differences between wheelchair-dependent and able-bodied subjects during wheelchair ergometry. *European Journal of Applied Physiology* 60:179-182, 1990.

Holt, K. G., **Hamill, J.**, Andres, R. O. The force driven harmonic oscillator as a model for human locomotion. *Human Movement Science* 9:55-68, 1990.

Hamill, J., McNiven, S. L. Reliability of ground reaction force parameters during walking. *Human Movement Science* 9:117-131, 1990.

Robertson, R. N., Osternig, L. R., **Hamill, J.**, DeVita, P. EMG-torque relationships during isokinetic dynamometer exercise. *Sports Training, Medicine and Rehabilitation* 2:1-10, 1990.

Holt, K. G., **Hamill, J.**, Andres, R. O. Predicting the minimal energy cost of human walking. *Medicine and Science in Sports and Exercise* 23(4):491-498, 1991.

Hamill, J., Freedson, P. S., Clarkson, P. M., Braun, B. Muscle soreness during running: biomechanical and physiological implications. *International Journal of Sports Biomechanics* 7(2):125-137, 1991.

Devita, P., Hong, D. M., **Hamill, J.** Effects of asymmetric load carrying on the biomechanics of walking. *Journal of Biomechanics* 24(12):1119-1129, 1991.

Ebbeling, C. J., **Hamill, J.**, Freedson, P. S., Rowland, T. W. Efficiency in Children's Gait. *Pediatric Exercise Science*. 4(1):36-49, 1992.

Widrick, J., Freedson, P. S., **Hamill, J.** Effect of internal work on the calculation of optimal pedalling rates. *Medicine and Science in Sports and Exercise* 24(3): 376-382, 1992.

Hamill, J., Bates, B. T., Holt, K. G. Timing of lower extremity joint actions during treadmill running. *Medicine and Science in Sports and Exercise* 24(7):807-813 1992.

Foti, T., Ebbeling, C. J., **Hamill, J.**, Ward, A., Rippe, J. Stair climbing machines: Lower extremity kinematics and exercise intensity comparisons. *Medicine, Exercise, Nutrition, and Health* 2:162-169, 1993.

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The influence of step aerobics on knee angle. Research Symposium at the IDEA Annual Conference, New Orleans, Louisiana, June 21, 1993.

Rearfoot motion in running. (with K. G. Holt and C. J. Edington). Symposium at the New England College of Sports Medicine Annual Meeting, Boxborough, MA, November 5, 1993.

Controversies in the calculation of mechanical energy. (with K. D. Browder and L. Darby). Biomechanics Academy Symposium at the American Alliance of Health, Physical Education, Recreation, and Dance Annual Meeting, Denver, CO, April 13, 1994.

Stability and rearfoot motion testing: A proposed standard. (with M. Milliron and J. Healy). VIIIth Biennial Meeting of the Canadian Society for Biomechanics, Calgary, Canada, August, 1994.

Stride Frequency and Foot Strike Impact. Dept. of Exercise and Sports Science. Arizona State University, December 8, 1994.

Biomechanics of functional footwear. (with M. Shorten). Pre-Conference Symposium at the International Society of Biomechanics Biannual Meeting, Jyväskylä, Finland, June, 1995.

Impact shock attenuation during conditions of altered stride frequencies in running. (with T. R. Derrick and K. G. Holt). Biomedical Engineering Society Meeting, Boston, MA, October, 1995.

Shoe and surface influences on ACL injuries. (with B. Busconi). American Volleyball Coaches Annual Meeting, Springfield, MA, December 15, 1995.

A force-driven harmonic oscillator model of human locomotion. German Sports University, Cologne, Germany, February 29, 1996.

If the shoe fits: the biomechanics of running shoes. American Medical Athletic Association, Boston, MA, April 12, 1996.

Biomechanics of athletic footwear. (with Martyn Shorten). American Alliance of Health, Physical Education, Recreation, and Dance Annual Meeting, Atlanta, GA, April, 1996.

An oscillator model of locomotion. University of Massachusetts Physics Department Seminar, Amherst, MA, May 1, 1996.

The mechanics of orthotics. New England Chapter of the American College of Sports Medicine Annual Meeting, Boxborough, MA, November 7, 1996.

A case study of a patient with patellofemoral pain. Eugene Michaels Lecture at the Combined Sections Meeting of the American Physical Therapy Association Annual Meeting, Dallas, Texas, February 14, 1997.

Oscillator Models of Human Locomotion. Korean Sports Science Institute, Seoul, Korea, October 15, 1997.

Lower extremity variability during running. Physical Therapy Department Seminar, University of Delaware, February 20, 1998.

Shock attenuation and transmission during running. (with T. R. Derrick). XVIIth Congress of the International Society of Biomechanics, Calgary, Alberta, Canada, August 12, 1999.

Variability and Stability: A Dynamical Systems Perspective. (with Van Emmerik, R. E. A., Heiderscheit, B., Li, L). Invited Symposium at the Annual Meeting of the American College of Sports Medicine, Indianapolis, IN, June, 2000.

From a Pendulum to a Spring. Department of Kinesiology, Louisiana State University, Baton Rouge, LA, October 24, 2000.

Oscillators and Springs. The Gladys Garrett Honor Lecture, Department of Exercise Science, University of Connecticut, Storrs, CT, May, 2001.

Joint Coupling variability and knee pain during running. (with B. Heiderscheit, R. Van Emmerik, J. Haddad). XVIIIth Congress of the International Society of Biomechanics, ETH Zurich, Switzerland, July, 2001.

Current Issues in Biomechanics. Beijing University, China, October 16, 2001.

Mechanical models and human locomotion. Beijing University, China, October 18, 2001.

A primer in 3-D: Considerations for biomechanical research. University of Las Vegas-Nevada, Las Vegas, Nevada, February 28, 2002.

Tibial stress fractures: A prospective study. Human Performance Laboratory, University of Calgary, Calgary, Alberta, Canada, November 29, 2002.

EXTERNAL FUNDING

Grants

1. Dynamics of platform diving, United States Diving Association, \$3,000, 1/1984 - 12/1984. 9/1985 - 6/1986.
2. Effects of anatomically variant foot-types on walking gait, ORDA, Southern Illinois University, \$6,000,
3. Effect of orthotic inserts on walkers with rearfoot and forefoot dysfunctions. Biomedical Research Support Grant, University of Massachusetts, \$6,000, 1/1987 - 1/1989.
4. Activity in later life: effects on posture and gait. National Institute of Aging, co-principal investigator, resubmitted January 28, 1988 (approved but not funded).
5. Musculoskeletal fitness norms for individuals aged 45-75. National Institute of Health, submitted February 1, 1988 (approved but not funded).
6. Mechanics of springboard diving: Modeling the diver-board system, United States Diving Association, \$15,000, 1/1989 - 1/1991.
7. Biomechanical analysis of military boots, (Grant #DAAK60-91-C-0102) U.S. Army, Natick, MA, \$183,000, 7/1991 - 12/1992.

8. Biomechanical analysis of military boots, (Grant #DAAK60-95-R-8010) U.S. Army, Natick, MA, (with Wellco Industries, North Carolina), \$51,436, 9/1995 - 12/1997.

9. Biomechanical analysis of military boots: Phase III, (Grant #DAAK60-95-R-8010) U.S. Army, Natick, MA, (with Wellco Industries, North Carolina), \$5,000, 9/1999 - 12/1999.

10. Biomechanical analysis of military boots. (Contract #DAAK16-00-P-0112) U.S. Army Soldier Systems Center, Natick, MA, \$25,000, 1/2000 - 6/2000.

11. Prospective study on tibial stress fractures. (Grant # DAMD17-00-1-0515), Department of the Army, (with Irene McClay). \$1,050,000, 8/1/2000 - 8/1/2004.

Contracts

1. Mechanics of lower extremity function, Isotechnologies, Inc., \$12,000, 9/1982 - 6/1984.

2. Ergonomics of lower extremity function, KangaROOS, USA, \$58,000, 9/1986 - 9/1989.

3. Prophylactic Knee and Ankle Bracing, AirCast Corp., \$20,000, 9/1988 - 9/1989.

4. Lower extremity action during exercise, Life-Fitness Group, \$6,000, 7/1990 - 7/1992.

5. Lower extremity mechanics, Hyde Athletic Shoe Company, \$279,000, 1/1989 - 1/1997.

6. Biomechanical analysis of golf equipment, Titleist and FootJoy Worldwide, \$283,000, 6/1992-12/1997.

7. Biomechanical analysis of hiking gait, The Timberland Company, \$15,000, 3/1995 - 10/1995.

8. A physiological profile of the game of field hockey. (with P. S. Freedson). United States Olympic Committee, Colorado Springs, Colorado, \$35,132, 1/1996 - 12/1996.

9. Locomotor patterns on running machines. NordicTrak, \$10,000, 9/1997-3/1998.

10. Plantar pressure patterns during hiking gait. The Timberland Company, \$42,000, 3/1998 - 5/1999

11. Investigation of foot scaling using a 3-D laser measurement system. Titleist and FootJoy Worldwide, \$50,000, 1/1999 - 12/2000

12. Biomechanical analysis of golf footwear, Titleist and FootJoy Worldwide, \$63,000, 1/1999-12/1999.

13. Walking and running mechanics and their effect on footwear, Hyde Athletic Shoe Company, \$33,000, 1/1999 - 12/1999.

14. In-shoe temperatures during hiking, The Timberland Company, \$15,000, 1/1999-3/1999.
15. Plantar forces during basketball movements, And1 Company, \$15,000, 1/1999-3/1999.
16. Rearfoot motion and shock attenuation in trial running footwear, The Timberland Company, \$10,000, 6/1999-7/1999.
17. Running mechanics and their effect on footwear. Hyde Athletic Shoe Company, \$33,000, 1/2000 - 12/2000.
18. Implementation of a 3-D laser measurement system. Titleist and FootJoy Worldwide, \$89,000, 1/2000 - 12/2000.
19. Shock attenuation in hiking footwear. The Timberland Company, \$18,000, 1/2000 - 6/2000.
20. Traction analysis of golf footwear. Titleist and FootJoy Worldwide, \$48,000, 1/2000 - 12/2000.
22. Footwear Testing. Titleist and FootJoy Worldwide. \$50,000, 1/2001 - 12/2001.
23. 3-D laser measurement system. Titleist and FootJoy Worldwide, \$89,000, 1/2001 - 12/2001.
24. Walking mechanics and their effect on footwear. Hyde Athletic Shoe Company, \$33,000, 1/2001 - 12/2001.
25. Modeling Parachute Landing Falls. Sub-contract from Foster-Miller, Inc., Waltham, MA, \$85,000, 1/2001 - 8/2003.
26. A new 3-D laser measurement system. Titleist and FootJoy Worldwide, \$69,000, 1/2002 - 12/2002.
27. Footwear Testing. Titleist and FootJoy Worldwide, \$50,000, 1/2002 - 12/2002.
28. Footwear Testing. Hyde Athletic Shoe Company, \$16,500, 1/2002 - 6/2002.
29. Footwear Testing, Timberland Company, \$24,000, 1/2002 - 12/2002.
30. Footwear Testing. Titleist and FootJoy Worldwide, \$124,000, 1/2003 - 12/2003.
31. Footwear Testing, Timberland Company, \$24,000, 1/2003 - 12/2003.